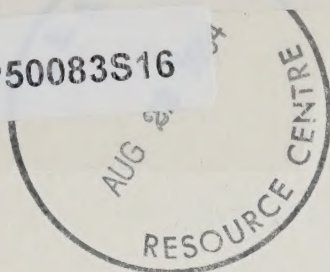


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A SAFETY AND RELIABILITY ANALYSIS OF ARCTIC PETROLEUM
PRODUCTION AND TRANSPORTATION SYSTEMS - A PRELIMINARY
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A SAFETY AND RELIABILITY ANALYSIS
OF
ARCTIC PETROLEUM PRODUCTION
AND TRANSPORTATION SYSTEMS
- A PRELIMINARY STUDY

A SAFETY AND RELIABILITY ANALYSIS
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AND TRANSPORTATION SYSTEMS
- A PRELIMINARY STUDY

by

FENCO CONSULTANTS LIMITED
Calgary, Alberta

This report is the result of a contract let under a spill prevention/contingency planning program of the Environmental Impact Control Directorate. Contributory funding was also provided by DIAND, DOT/DRSS and EMR/CANMET. This unedited version is undergoing a limited distribution to transfer the results to people working in related studies.

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ABSTRACT

Three areas of the Canadian Arctic hold great potential for petroleum resource development. These areas: the southern Beaufort Sea, the Arctic Islands and the Labrador Shelf represent extreme challenges in their severe physical environment. Ice, waves and storms constrain all development activities and are necessitating new production systems, new ice breaking technology and new ice resistant production carriers.

In this environment, the reliability of the systems and the production and transportation operations are of essential concern. The risk of accidental hydrocarbon discharges which may result in environmental damage must be minimized.

This report has been prepared to present the results of a preliminary study to assess the potential risks from petroleum production and transportation activities on the Arctic environment. The study provides safety and reliability analyses of the systems being considered for use by the industry.

The results of the analyses have been developed in a form which identifies the type and probable magnitude of the risks. Recommendations for improvements in safety and the requirements for further research are presented.

SUMMARY

The impact of a major oil spill on the shorelines of the Canadian Arctic could have serious and far reaching long-term effects. This report presents a preliminary assessment of the risks to the Arctic environment due to oil spills from petroleum production and transportation activities.

The study has used probability analysis techniques to identify environmental risks for the proposed Arctic resource development projects. Systems being considered for use in these developments have been reviewed to identify risk areas and to provide information and recommendations for the improvement of safety and reliability. The results of these analyses are presented to indicate the type and probable magnitude of the risks to the Arctic environment. Aspects requiring further research are outlined where gaps in available information will demand further study.

For the purposes of analysis of the production systems, the study area has been divided into four regions:

- Beaufort Sea, Shallow Water

- Beaufort Sea, Deep Water

- Arctic Islands

- Labrador Sea

The selection of the most likely Arctic petroleum production and transportation systems in these regions has been based on interviews and discussions with industry representatives and on a review of relevant publications. In some areas, several alternative schemes are contemplated with differences at each stage of development. The systems described in the report are then based on judgement.

Similarly, the number of wells and production levels have been based on discussions and judgement for each region. Production capacities used in the study are intended to represent early stages of development.

The transportation system assumed for this production is based on a fleet of eight tankers each of 200,000 DWT with double hulls, ice reinforced.

For each region, the production systems which have been assumed are summarized as follows:

Beaufort Sea, Shallow Water:

Drilling and production from caisson islands.

Total of ten production wells.

Beaufort Sea, Deep Water:

Drilling and production from Arctic Production and Loading Atoll (APLA).

Total of twenty production wells.

Arctic Islands:

Drilling from ice platforms.

Production from subsea systems with subsea pipeline to shore.

Total of ten production wells.

Labrador Sea:

Drilling from floating production platform.

Production from subsea template systems.

Total of ten production wells.

Components in the production and transportation systems were reviewed to identify the associated hazards. In production, the causes of oil spills were classified into the following categories:

Blowouts

Rig Spills

Other System Spills

Pipeline Spills

In transportation, the causes of spills were identified in the following categories:

Collision
 Grounding
 Structural Failure
 Other

For each of these causes of oil spills, available statistical data were reviewed and modified for application to arctic development. The probabilities of spills of different sizes were established in the following classification for each cause:

10 -	100 m ³
100 -	1,000 m ³
1,000 -	10,000 m ³
10,000 -	100,000 m ³
100,000 -	1,000,000 m ³

The probability analysis indicates that, considering the accuracy of the data base, the four regions have about the same level of oil spill risk. Overall, on a per well-year basis, the Beaufort Sea Deep system is shown to be safest, followed by Beaufort Sea Shallow, Arctic Islands and Labrador Sea systems.

In general, the oil spill risk for the production systems is substantially lower than the oil spill risk for tanker transport. This is particularly noted for large spills. Pipelines are also identified as a major source of spills. For the Arctic Islands system, the proposed subsea pipeline creates significant risks.

To assess the environmental impacts of the oil spills identified in the probability analyses, nine hypothetical spill sites were selected. The selection was based on the production regions and transportation routes assumed earlier, and included the following sites:

Mackenzie Bay
 Beaufort Sea
 Armstrong Point
 Viscount Melville Sound

Sverdrup Basin
Allison Inlet
Cape Liddon
Cape Hay
Cape Harrison

Potential impacts were considered at each site in each season for the following resource groups:

Plankton and Invertebrates
Fish
Birds
Marine Mammals

Impacts on resource utilization, hunting and fishing were also considered.

To establish the movement and maximum surface extent of the oil spills, elementary slick modelling was used with conservative assumptions to give a worst case trajectory for each site.

Impact levels were based on a simplified classification system of major, moderate, minor and negligible. A further classification of "insufficient information" was used to indicate tentative designations resulting from limited data. Site by site descriptions of the probable impacts on the marine environment are presented in the appendices.

The study concludes that with anticipated advances in technology to provide adequate protection against the hazards, there should be no insurmountable obstacles to arctic production and transportation of petroleum.

VOLUME 1 - PRELIMINARY STUDY

TABLE OF CONTENTS

	PAGE
ABSTRACT	i
SUMMARY	ii
TABLE OF CONTENTS	vi
LIST OF FIGURES	ix
LIST OF TABLES	x
1. INTRODUCTION	1-1
2. THE MOST LIKELY ARCTIC PETROLEUM PRODUCTION AND TRANSPORTATION SYSTEMS	2-1
2.1 Introduction	2-1
2.2 The Most Likely Arctic Petroleum Production Systems	2-1
2.2.1 Beaufort Sea (Shallow Water)	2-1
2.2.2 Beaufort Sea (Deep Water)	2-2
2.2.3 Arctic Islands	2-3
2.2.4 Labrador Sea	2-6
2.3 The Most Likely Arctic Petroleum Transportation Systems	2-8
2.3.1 Beaufort Sea (Shallow Water)	2-8
2.3.2 Beaufort Sea (Deep Water)	2-9
2.3.3 Arctic Islands	2-9
2.3.4 Labrador Sea	2-10
3. SPILL PROBABILITIES FOR PRODUCTION AND TRANSPORTATION SYSTEMS	3-1
3.1 Introduction	3-1
3.2 Reliability of the Production Systems	3-1
3.2.1 Definition of the Components of the Production Systems and Associated Hazards	3-1
3.2.1.1 Drilling Systems	3-1
3.2.1.2 Well-Site Systems	3-2
3.2.1.2.1 Subsea Equipment	3-2
3.2.1.2.2 Production Platforms	3-3
3.2.1.2.3 Well Servicing and Workover	3-4

	PAGE
3.2.1.3 Gathering Systems	3-4
3.2.1.4 Processing Systems	3-5
3.2.1.5 Storage Systems	3-5
3.2.1.6 Product Transfer Systems	3-6
3.2.2 Risk Assessment Methodology	3-6
3.2.3 Results of Analysis	3-9
3.2.3.1 General	3-9
3.2.3.2 Blowouts	3-12
3.2.3.3 Development Drilling and Well Completion	3-19
3.2.3.4 Start-Up and Steady State Production	3-20
3.2.3.5 Abandonment	3-24
3.2.3.6 Combined Probability Tables	3-25
3.3 Reliability of the Transportation Systems	3-26
3.3.1 The Ship Transportation System	3-26
3.3.1.1 Ship Traffic Versus Region	3-26
3.3.1.2 Ship Hazards	3-27
3.3.1.3 Data Sources	3-27
3.3.1.4 Description of the Logic for the Ship Transportation System	3-28
3.3.2 Grounding	3-29
3.3.2.1 Causes of Grounding	3-29
3.3.2.2 Estimation of Grounding Hazards - Data Base	3-30
3.3.2.3 Scaling of Data Base to Reflect Ships and Area Studied	3-31
3.3.3 Collision	3-32
3.3.3.1 Causes of Collision	3-32
3.3.3.2 Data Base and Assumptions Related to Collision	3-33
3.3.4 Ramming	3-34
3.3.5 Structural Failure	3-34
3.3.6 Other Categories	3-35
3.3.7 Damage by Ice	3-35
3.3.8 Tables Summarizing Probabilities	3-36
4. ENVIRONMENTAL CONSEQUENCES OF HYDROCARBON SPILLS	4-1
4.1 Introduction	4-1
4.2 Plankton/Invertebrates	4-1
4.3 Slick Modelling	4-2
4.4 Environmental Impacts	4-2
4.5 Sites	4-3

	PAGE
Site 1 Mackenzie Bay	4-3
Site 2 Beaufort Sea	4-4
Site 3 Armstrong Point	4-5
Site 4 Viscount Melville Sound	4-5
Site 5 Sverdrup Basin	4-6
Site 6 Allison Inlet	4-6
Site 7 Cape Liddon	4-7
Site 8 Cape Hay	4-7
Site 9 Cape Harrison	4-8
5. CONCLUSIONS AND RECOMMENDATIONS	5-1
5.1 Introduction	5-1
5.2 Information for Production and Transportation Planning	5-2
5.3 Environmental Data	5-4
5.4 Safety and Reliability Requirements	5-6
5.5 Conclusions	5-7
6. REFERENCES	6-1
7. ACKNOWLEDGEMENTS	7-1

VOLUME 2 - APPENDICES

APPENDIX A - ENVIRONMENTAL CONSEQUENCES OF HYDROCARBON SPILLS

APPENDIX B - ENVIRONMENTAL DATA SUMMARIES

LIST OF FIGURES

<u>FIGURE NUMBER</u>	<u>TITLE</u>	<u>FOLLOWING PAGE</u>
1-1	Arctic Production Fields and Shipping Route	1-3
1-2	Selected Sites for Environmental Studies	1-3
2-1	Beaufort Sea Production Area	2-1
2-2	Arctic Islands Production Area	2-3
2-3	Labrador Sea Production Area	2-6
2-4	Beaufort Sea Shipping Route	2-8
2-5	Arctic Islands Shipping Route	2-9
2-6	Labrador Sea Shipping Route	2-10
3-1	Elementary Fault Tree for an Oil Spill	3-7
3-2	Elementary Fault Tree for Oil Spill - Drilling	3-8
3-3	Elementary Fault Tree for Oil Spill - Production	3-8
3-4	Elementary Fault Tree for Oil Spill - Abandonment	3-8
3-5	Number of Icebergs Sighted by the International Ice Patrol	3-17
3-6	Shipping System Risk Methodology	3-28
3-7	Typical Profile of Ship's Track after Repeated Passages (On)	3-30

LIST OF TABLES

<u>TABLE NUMBER</u>	<u>TITLE</u>	<u>FOLLOWING PAGE</u>
3.1	Number of Blowouts Recorded - Gulf of Mexico and North Sea	3-14
3.2	Blowout Event Probabilities with Upper and Lower Bounds	3-14
3.3	Estimate Blowout Probabilities for all Regions and Phases	3-18
3.4	Probabilities of Rig Spills by Size and Region - Drilling	3-20
3.5	Probabilities of Rig Spills by Size and Region - Production	3-21
3.6	Systems Spill Probabilities by Size and region - Production	3-23
3.7	Pipeline Spill Probability - Arctic Islands	3-24
3.8	Probabilities of Oil Spills - Abandonment	3-25
3.9-3.23	Combined Division Probability Tables	3-26
3.24	Overall Spill Probabilities for Drilling and Production Systems	3-26
3.25	Canada Coast Guard Termpol 1969-1974	3-31
3.26	Poricelli; et al	3-31
3.27	Henry	3-31
3.28-3.37	Spill Probabilities for Transportation Systems	3-36

1. INTRODUCTION

The three areas of the Canadian Arctic thought to hold the greatest potential for petroleum exploitation are the southern Beaufort Sea, the Arctic Islands and the Labrador Shelf. Ice, icebergs, waves and storms create considerable obstacles to operations and necessitate modification and strengthening of conventional production systems and the design of new icebreaking or ice resistant ships and product carriers.

This report has been prepared to provide a general overview of the likely oil spill risks of the most likely petroleum production and transportation systems that may be used in the Arctic. The report also identifies information gaps which lead to uncertainties in the estimates of risks and environmental impacts. Recommendations presented deal primarily with the improvement of data gathering, storage and collation and finally, data analyses procedures which would lead to better and more reliable assessment of hazards.

The primary objectives of this preliminary study can be summarized as follows:

1. To provide a safety analysis of the production and transportation systems contemplated by the industry for the Arctic hydrocarbons.
2. To provide a reliability analysis of proposed petroleum production and transportation systems for the Arctic conditions.
3. To assess the environmental risks and to recommend better methods for their prediction and minimization.

In meeting these objectives, the following specific tasks have been undertaken in the course of the study:

1. The most likely Arctic petroleum production and transportation systems have been identified and defined. The production fields and shipping routes are shown on Figure 1-1.

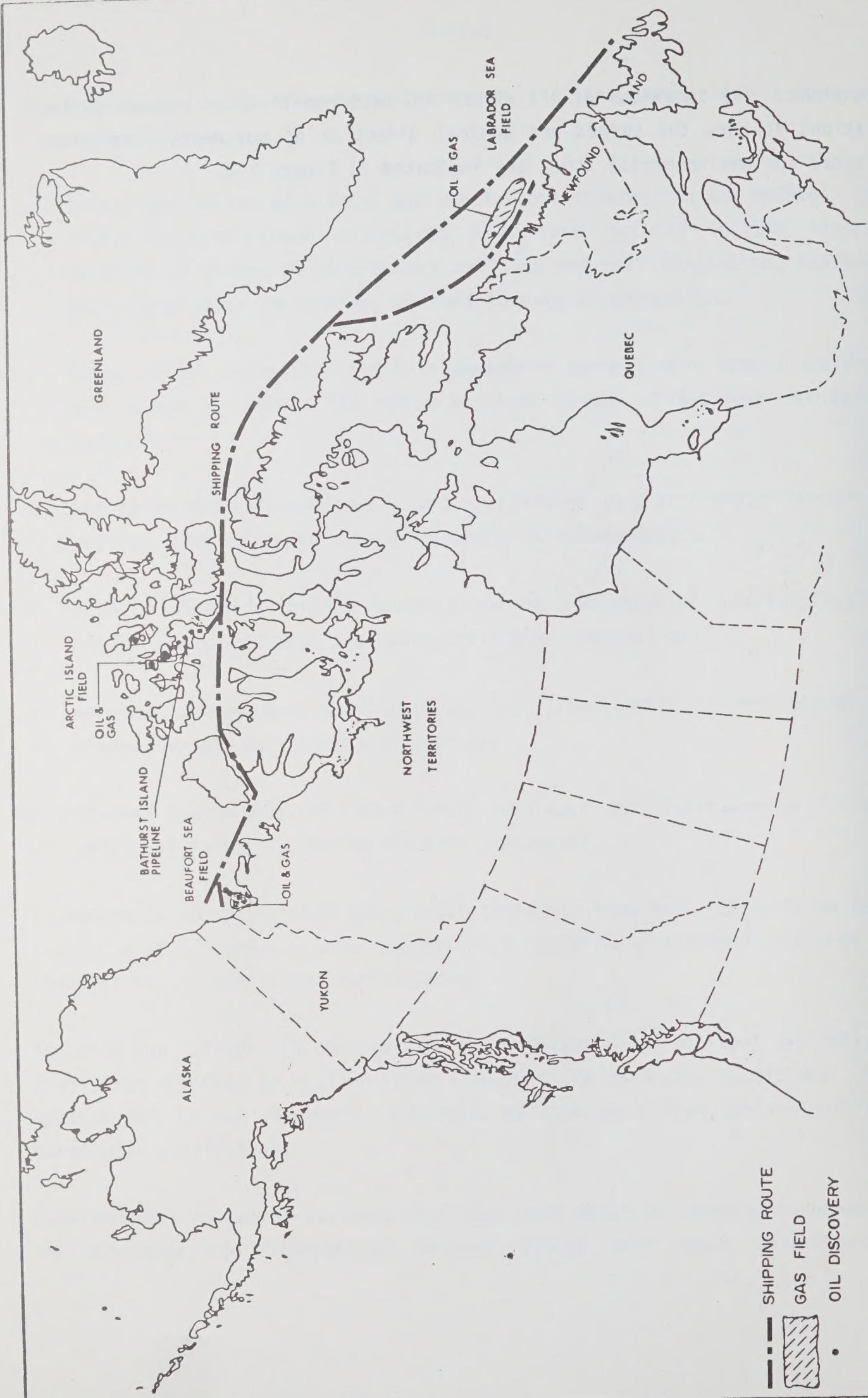
2. Components in these systems have been analysed using risk assessment methodology.
3. Using appropriate analytical and statistical information and methods, the risks of hydrocarbon discharges have been defined in the several operational phases of development drilling and well completion, start-up and steady state production, and abandonment of production.
4. Risks in the production and transportation systems have been classified and ranked to assess the relative significance of different kinds of hazards.
5. Safety improvement measures have been reviewed in a preliminary manner to provide information for the development of recommendations.
6. Aspects requiring further research for the reduction of uncertainties in design and operational procedures have been identified.
7. Recommendations have been developed for improvements in the design of production and transportation systems.
8. General recommendations have been developed for improvements in the safety of operation and maintenance procedures.

To determine the production and transportation systems most likely to be used in the Arctic, opinions were sought from individuals actively involved in planning Arctic operations for industry.

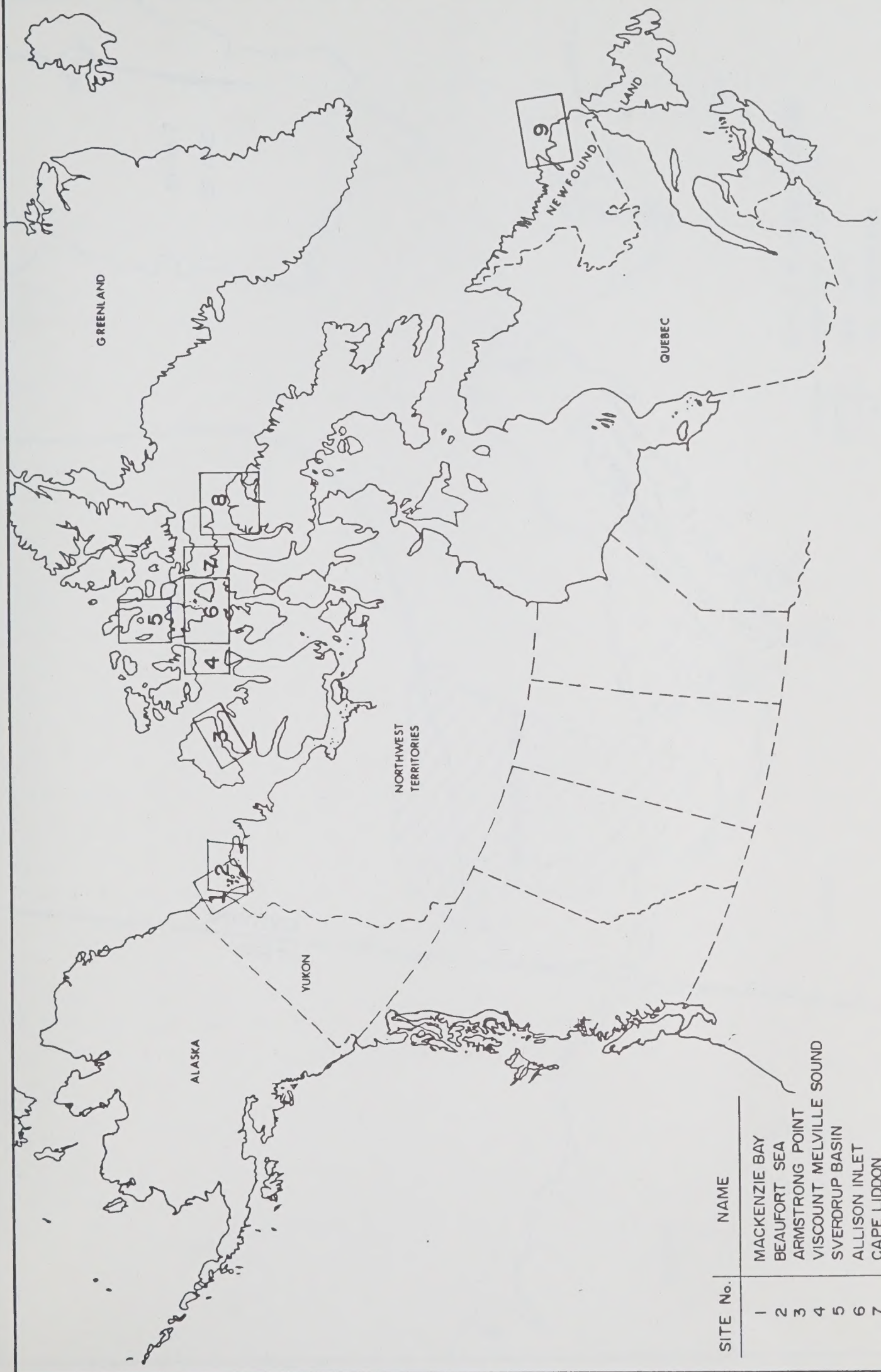
The risk and reliability analyses are based on worldwide accident and failure statistics modified by scaling factors appropriate to Arctic conditions. For systems not in use elsewhere, estimates of risk have been derived for the particular application.

Environmental impact assessments have been made based on existing information to determine the interaction between slicks and local environmental

conditions. The behaviour of oil slicks has been modelled for representative locations to show the spread and general direction of movement. The sites selected for environmental study are indicated in Figure 1-2.



ARCTIC PRODUCTION FIELDS
& SHIPPING ROUTE



SITE No.	NAME
1	MACKENZIE BAY
2	BEAUFORT SEA
3	ARMSTRONG POINT
4	VISCOUNT MELVILLE SOUND
5	SVERDRUP BASIN
6	ALLISON INLET
7	CAPE LIDDON
8	CAPE HAY
9	CAPE HARRISON

SELECTED SITES FOR
ENVIRONMENTAL STUDIES
FIG. 1-2

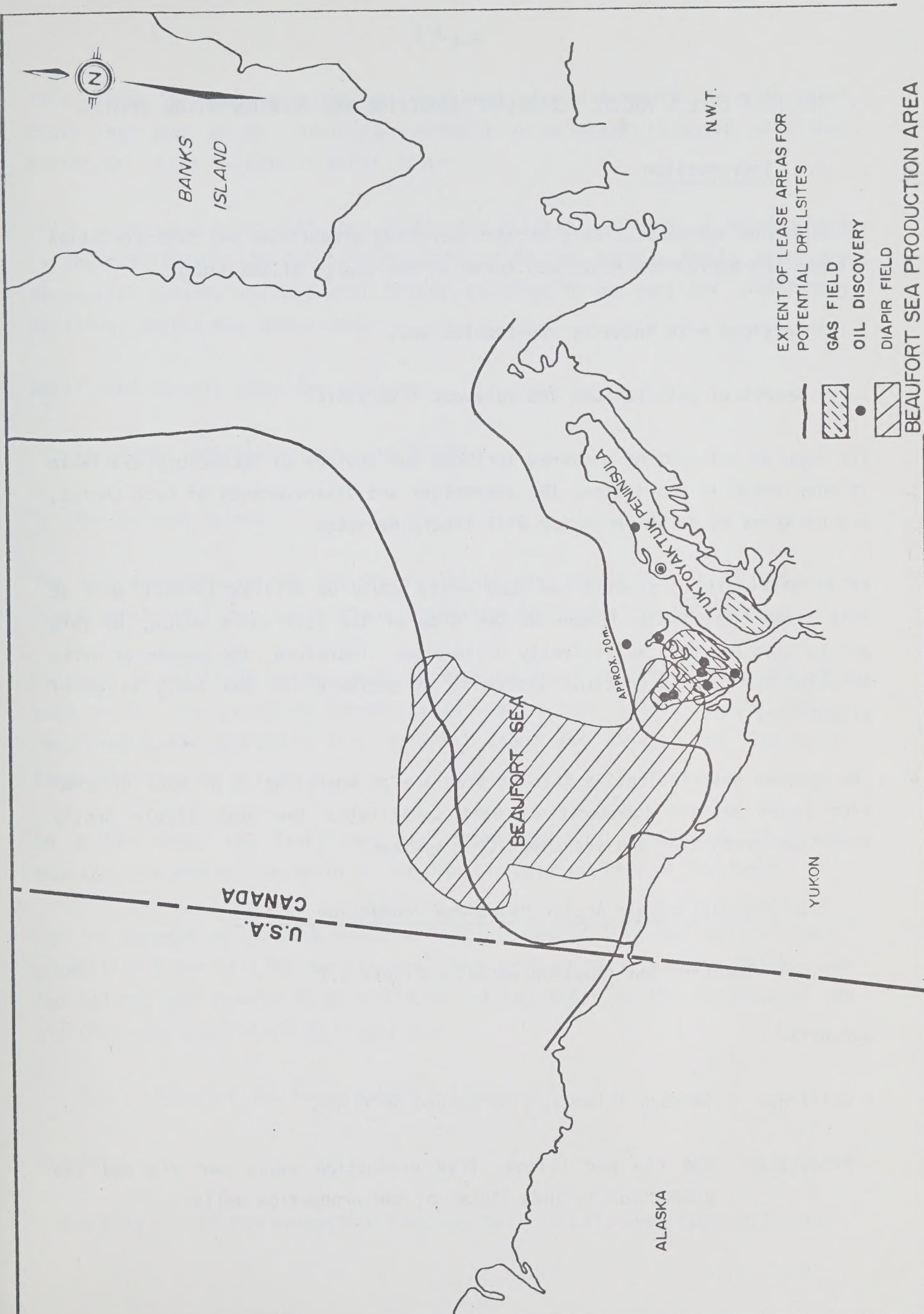


FIG. 2-1

2. THE MOST LIKELY ARCTIC PETROLEUM PRODUCTION AND TRANSPORTATION SYSTEMS

2.1 Introduction

To determine the most likely Arctic petroleum production and transportation systems two approaches have been taken in the course of the study:

Interviews with industry representatives.

A search of publications and relevant literature.

The type of information gathered included the choices of technology available at each stage in the system, the advantages and disadvantages of each choice, and opinions as to which choice will likely be taken.

It is difficult to predict how many wells would be drilled in each area at this time. This will depend on the size of the reservoirs which, to this point, have not been sufficiently delineated. Therefore, the number of wells selected for each production system is an estimate for the early stage of production.

The systems descriptions in this chapter are an amalgamation of this information based on our judgement of what constitutes the most likely Arctic petroleum production and transportation systems.

2.2 The Most Likely Arctic Petroleum Production Systems

2.2.1 Beaufort Sea (Shallow Water) - Figure 2.1

Synopsis:

- Drilling: Caisson islands, year around drilling.
- Production: One rig per island, five production wells per rig and two production islands (total of ten production wells).

This region is intended to include that part of the Beaufort Sea with water depth less than 20 m. Drilling currently in progress is based on either artificial earth islands or drill ships.

Drill ships have lower cost than artificial islands. However, a disadvantage is their difficulty in maintaining position in ice cover. Drill ships are seasonally constrained and will likely continue to be used for exploratory drilling, during the summer only.

Artificial islands offer two choices:

The earth (gravel) island, now in use.

The caisson island.

The main advantage of the artificial island over the drillship is its year-round serviceability - an economic necessity for production operations.

Caissons to retain an island could be made of steel or concrete and sit on a sand berm. The principal advantage of the caisson island is the reduced requirement for hydraulic fill material (sand and gravel) and the faster construction.

In either case, the facilities and procedures for production, drilling, storage, and processing would be similar to these on land or platforms.

For the purpose of the risk study we have assumed that in the early stages of production there will be two islands, each with five production wells. The two islands are assumed to be built in shallow water in the vicinity of the oil discovery area shown in Figure 2.1.

2.2.2 Beaufort Sea (Deep Water) - Figure 2.1

Synopsis:

- Drilling: Arctic Production Loading Atoll (APLA), year-round drilling.

- Production: Land-based directional wells. Two APLA, two rigs per APLA, five production wells per rig (total of 20 production wells).

This region includes the production area of the Beaufort Sea with depths greater than 20 m. Drill ships are not considered for production drilling since they are unlikely to be useable year-round.

The Arctic Production and Loading Atoll (APLA) is the most promising and currently the most favoured integrated concept for deeper water in the Beaufort Sea. The APLA would be built in two sections, using caissons to form a protected harbour which would be used by ice-breaking tankers for loading oil.

The interior dimensions of the harbour will be large enough to allow tankers to turn within the atoll. There will be sufficient space on the APLA islands to support the drill rigs. Drilling procedures will be equivalent to those used on land for directional drilling.

Production, processing and storage facilities will be supported on the atoll. These facilities will use conventional production technology.

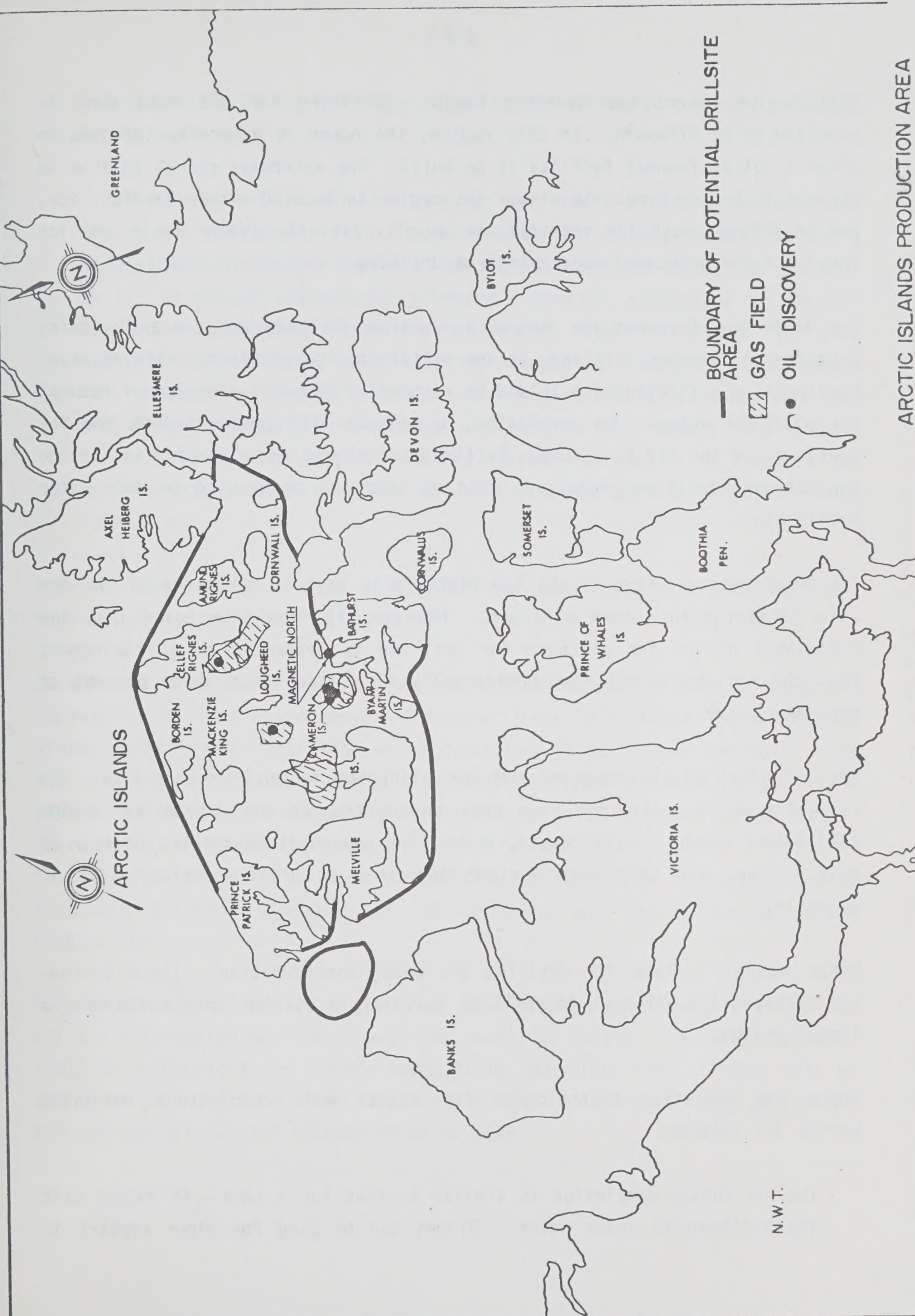
At a later stage of production, the APLA could be the centre of a cluster of islands. Subsea gathering lines would come into the APLA for storage and shipping.

For the purpose of the risk study we have assumed that in the early stage of production there will two APLA's with no surrounding production islands.

2.2.3 Arctic Islands - Figure 2.2

Synopsis:

- Drilling: Ice platform, drilling during winter only.
- Production: Subsea.



ARCTIC ISLANDS PRODUCTION AREA

This region covers the Sverdrup Basin. Drilling for the most part is expected to be offshore. In this region, the ocean is generally too deep to allow a bottom founded facility to be built. The waterways can at no time be assumed to be ice free. In winter the region is located within landfast ice, and in summer, pack ice vestiges are usually present. Water depth and ice cover are the principal constraints on drilling.

The technique favoured for future production drilling and presently being used for exploratory drilling, is the artificial ice platform. This involves constructing a floating ice island by controlled flooding a region of natural ice with sea water. On completion, a moonpool is opened through the ice platform and the rig is raised. Drilling techniques are a combination of the conventional drilling techniques used on land and those used on deep water drill ships.

The principal advantage of the ice platform is that it makes use of the ice as a benefit rather than a hazard. However, it should be noted that the usefulness of the ice platform for drilling is dependent on a requirement that the ice should not move horizontally more than about seven percent of the water depth.

The principal disadvantage of the ice platforms is their seasonality. As currently being built, they can only be constructed and maintained in the cold winter months. As a result, a drilling season is restricted to four or five months, and this must include the time to drill a relief well if necessary.

Other support systems for drilling are under consideration. These include air cushion rigs which would still be seasonal in use but they could have a longer season.

There are competing technologies for subsea well completions involving wet or dry systems:

The wet subsea completion is similar to that for a land well except that the wellhead is under water. Divers can be used for minor repairs to

depths of 150-200 m. For major repairs, the wellhead is normally brought to the surface.

A dry subsea well completion has an additional pressure vessel built around the wellhead. This allows pressurized diving vessels to carry specialized maintenance personnel to the wellhead and to work on the well in air at normal atmospheric pressure. Overall advantages of the dry completion technology are the provisions for additional in situ maintenance procedures, which simplify overall well servicing and improve well reliability. Dry subsea well completion is a relatively new technology and at this time does not have a long established service record. It is also costly. The dry system would be of no interest for shallow water wells, and only of real interest at depths greater than 200-300 m.

Overall, the wet system is considered the most likely method for well completions in the Arctic Islands.

In the Arctic Islands, subsea mechanical equipment must be kept to a minimum because of the ice environment. For near shore oil fields the production system would involve satellite wells gathering to an onshore manifold. For oil fields far from shore the system would utilize multi-well subsea templates and subsea manifold with gathering lines to the processing facilities. There would be one basic processing system for each field of oil. Processing installations and storage would probably be on land. Some processing may be necessary offshore depending on the distance and the production fluid composition.

For the purpose of the risk study we have assumed that there will be one oil field producing near shore with ten satellite wells. The satellite wells would be connected to an onshore manifold by gathering lines. These will be buried at the shoreline tidal boundary to avoid ice scour. The processing and storage systems are assumed to be on land.

The assumption of near shore oil field production is based on the oil discoveries to date. These are close to Cameron Island, shown on Figure 2.2.

2.2.4 Labrador Sea - Figure 2.3

Synopsis:

- Drilling: Floating production platform provided with dynamic positioning and propulsion equipment. Year-round drilling with some interruptions due to severe ice conditions.
- Production: Two five-well subsea production template systems deposited in a "glory hole" (total production from ten wells).
- Gathering: Gathering lines route oil production to a floating production platform at the surface.
- Processing: Processing facilities aboard the floating production platform.
- Storage: Storage facilities aboard a floating vessel, detachable from the production facilities to drift with a loading tanker. The storage vessel will be provided with propulsion.

In most of the Labrador Sea region the water is too deep and the pack ice and iceberg movements are too heavy to allow drilling to be performed economically from anything other than a floating vessel.

The three alternatives to the floating production system are:

A gravity structure on an artificial mound.

An all-subsea production system connected to a multi-phase pipeline to shore.

A single ship-shape production platform.

In shallow water, a gravity structure on an artificial mound would be designed to withstand iceberg collisions. This would have applicability in a restricted zone of production.

The all-subsea production system is feasible for water depths beyond 300 m, below the deepest level at which iceberg scours take place.

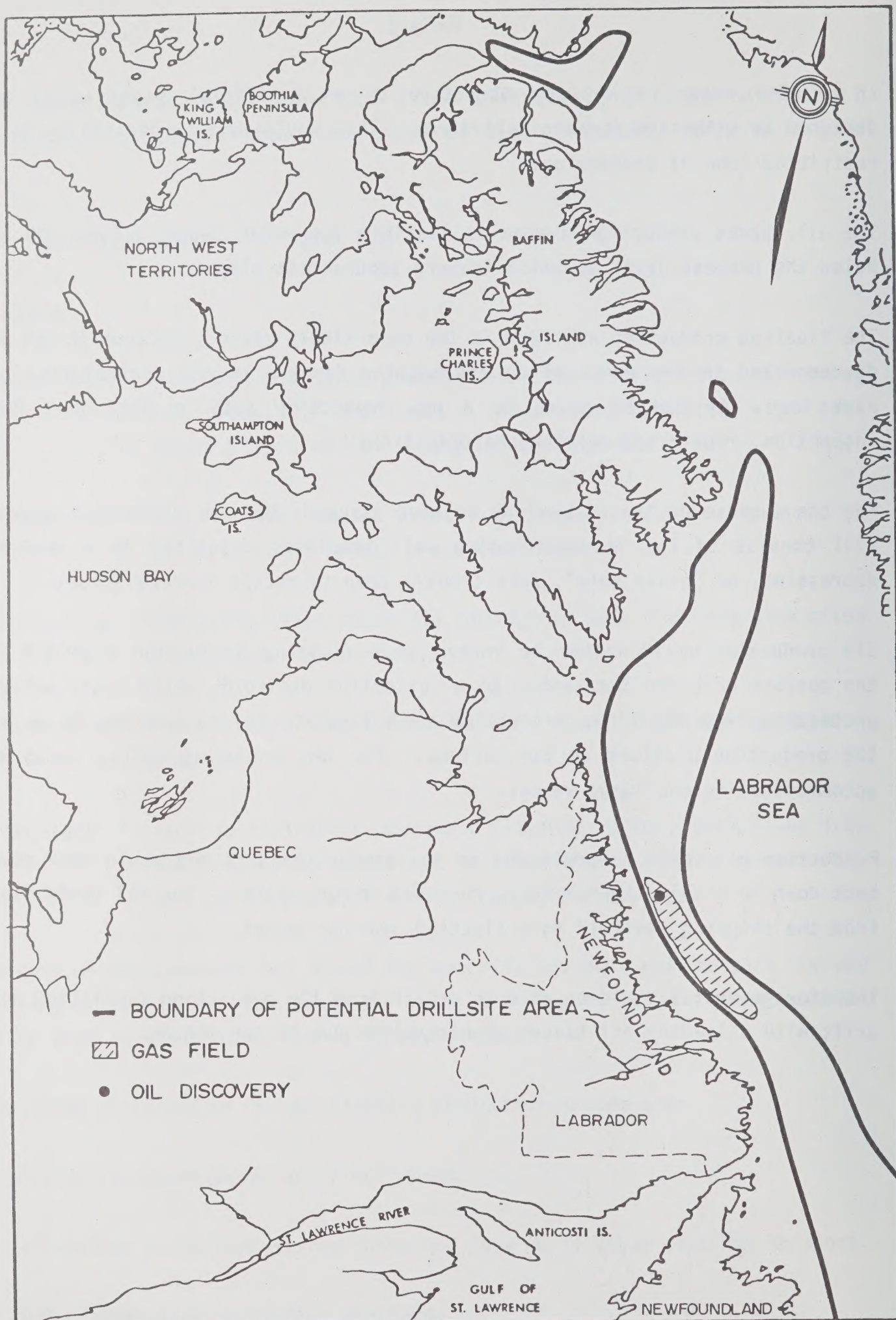
The floating production platform is the more likely system, because it can be disconnected in the event of an approaching iceberg or the accumulation of pack ice. It can be moved to a new production site or into port for inspection, repair and maintenance operations.

For the purpose of the risk study we have assumed that the production system will consist of two five-production well templates deposited in a dredged depression, or "glory hole", sufficiently deep to escape iceberg scours.

Oil production would either be routed to a floating production platform at the surface or under the seabed to a collection manifold, which would accept production from the other production well template before sending it up to the production platform on the surface. The ten producing wells, could be accommodated by one large vessel.

Production oil could be processed on the production unit and would then move back down to a shipping manifold, recessed in the seabed. The oil would flow from the shipping manifold to a floating storage vessel.

The storage vessel would be able to detach from the production facilities and drift with a loading oil tanker when required due to ice threat.



LABRADOR SEA PRODUCTION AREA

2.3 The Most Likely Arctic Petroleum Transportation Systems

2.3.1 Beaufort Sea (Shallow Water) - Figure 2.4

Synopsis:

- Tanker oil carrier through Prince of Wales Strait, Parry Channel, Lancaster Sound, Davis Strait to east coast markets.
- Loading directly from artificial islands.
- Class 10 icebreaking tanker, 200,000 DWT.

There are two alternatives for oil transportation from the Beaufort Sea:

An overland pipeline.

A tanker route eastward.

A westward route is constrained by the continuous ice pack of the Arctic Ocean. Eastward tanker traffic would be restricted to an intra-archipelago route.

Tanker transport has two advantages over a pipeline:

More flexible marketing capability.

Lower initial capital cost.

The disadvantage at the present time is the untested and unproven technology of a Class 10 icebreaking tanker system.

For the purpose of the risk study, we have assumed that at the early stage of development in the Beaufort Sea (Shallow Water), production would be serviced by two ships operating year-round. Each ship would make fifteen round trips per year.

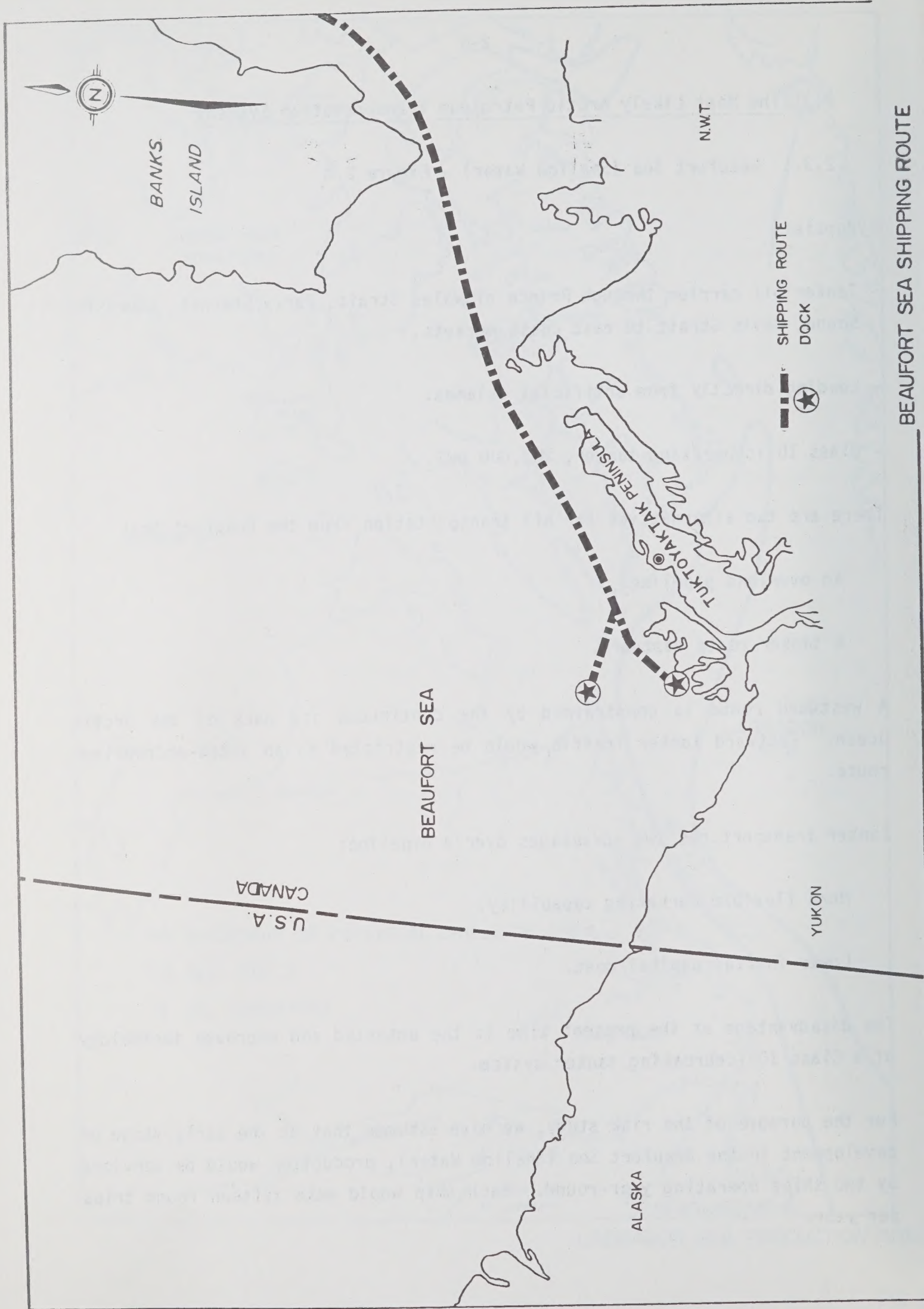


Figure 2.4 shows the location of the most likely loading facilities for the production system in the Beaufort Sea Shallow Water.

2.3.2 Beaufort Sea (Deep Water)

Synopsis:

- Tanker oil carrier through Prince of Wales Strait, Parry Channel, Lancaster Sound, Davis Strait to east coast markets.
- Loading from Arctic Production and Loading Atoll.
- Class 10 icebreaking tanker 200,000 DWT.

The Beaufort Sea deep water transportation system is virtually identical to that for the Beaufort Sea Shallow Water region. The over-land pipeline alternative would require a short haul tanker feeder system.

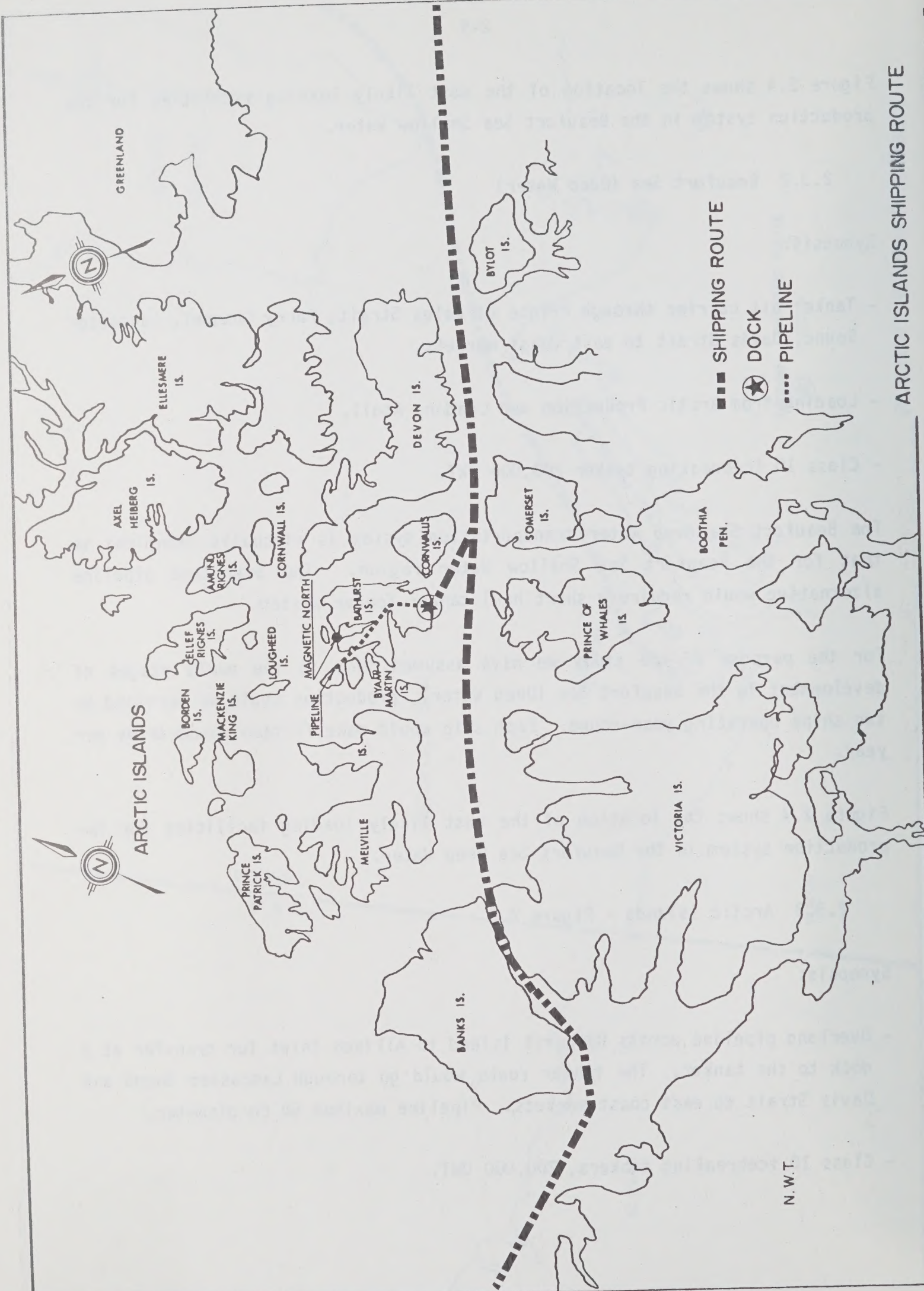
For the purpose of the study we have assumed that in the early stages of development in the Beaufort Sea (Deep Water), production would be serviced by two ships operating year-round. Each ship would make fifteen round-trips per year.

Figure 2.4 shows the location of the most likely loading facilities for the production system in the Beaufort Sea Deep Water.

2.3.3 Arctic Islands - Figure 2.5

Synopsis:

- Overland pipeline across Bathurst Island to Allison Inlet for transfer at a dock to the tanker. The tanker route would go through Lancaster Sound and Davis Strait to east coast markets. Pipeline maximum 60 cm diameter.
- Class 10 icebreaking tankers, 200,000 DWT.



ARCTIC ISLANDS SHIPPING ROUTE

For the Arctic Islands three transport systems were considered:

- 1) an island hopping pipeline connecting into a long-haul pipeline originating in the Mackenzie Delta,
- 2) short-haul pipelines and tankers off-loading into the Mackenzie Delta long-haul pipeline,
- 3) short-haul pipelines feeding long-haul tankers at Allison Inlet.

As for the Beaufort Sea, the long-haul tanker approach is considered most likely, due to economic considerations.

A pipeline across Bathurst Island is considered likely since it avoids the problems of highly variable multi-year pack ice found in the potential production area of the Sverdrup Basin.

For the purpose of the study we have assumed a 60 cm pipeline across Bathurst Island with a length of 250 km, 200 km on land and 50 km offshore. There would be a storage-transfer facility located at Allison Inlet. In the early stage of development in the Arctic Islands, production would be served by two Class 10 icebreaking tankers each making fifteen round-trips per year.

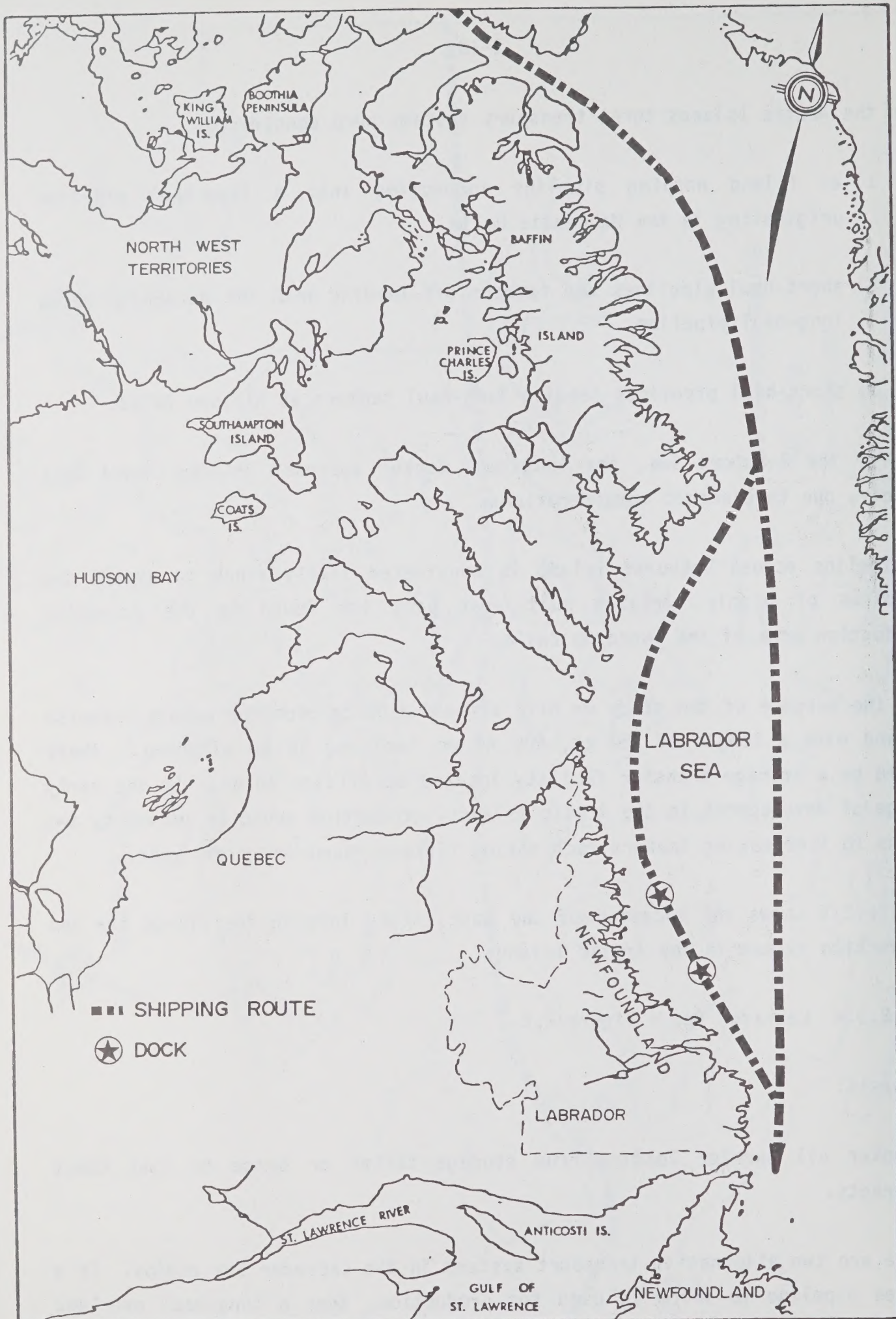
Figure 2.5 shows the location of the most likely loading facilities for the production system in the Arctic Islands.

2.3.4 Labrador Sea - Figure 2.6

Synopsis:

- Tanker oil carrier loading from storage tanker or barge to East Coast markets.

There are two alternative transport systems in the Labrador Sea region. If a subsea pipeline to shore is used for production, then a long-haul overland pipeline could be used. A subsea pipeline is considered unlikely due to



LABRADOR SEA SHIPPING ROUTE

difficulties of trenching and burial in boulders. The remaining choice uses the tanker oil carrier.

For the purpose of the study we have assumed that in the early stages of production, two Class 10 icebreaking tanker carriers of 200,000 DWT will each make fifteen round-trips per year.

3. SPILL PROBABILITIES FOR PRODUCTION AND TRANSPORTATION SYSTEMS

3.1 Introduction

This chapter describes the components of the Production and Transportation systems and their associated hazards. The risk assessment methodology is presented and illustrated with flow charts. The results of the risk analysis are then summarized for each of the systems which were discussed in the previous chapter.

3.2 Reliability of the Production Systems

For the purpose of the analysis of the production systems the study area considers four regions:

- Beaufort Sea (Shallow Water)
- Beaufort Sea (Deep Water)
- Arctic Islands
- Labrador Sea

3.2.1 Definition of the Components of the Production Systems and Associated Hazards

3.2.1.1 Drilling Systems

Offshore drilling procedures are generally similar to those used onshore with modifications and additional equipment to suit the type of platform being used. These include risers, compensators and special wellhead equipment. Earth island platforms may use standard land based rigs with few changes.

The procedures for drilling offshore wells are explained in various publications (Trade Journals and Conference Proceedings such as OTC). They vary from region to region, operator to operator and hole to hole so details will not be given here.

Items which must be analysed in regard to hazards are:

1. Setting the Surface Casing.
2. Testing and Installation of the Blowout Preventor (BOP).
3. Setting and Connecting the Marine Riser.
4. Downhole Pressure Control.
5. Directional Drilling.

Other hazards for drilling in the Labrador Sea are pack ice and the massive icebergs which drift down Davis Strait from Greenland. In the Arctic Islands ice motions are also a hazard to drilling from ice platforms.

During normal operations, small spills do occur due to leaks, minor accidents and mishaps on the rig. These spills are usually the result of human carelessness or minor mechanical failures. Included in this category would be such spill causing accidents as the improper closure of a valve or the bursting of a drum of fuel dropped from a load or storage area.

3.2.1.2 Well-Site Systems

3.2.1.2.1 Subsea Equipment

Subsea equipment includes casing, BOP stacks, marine risers, motion compensators, flow controls and product gathering lines.

Methods used to set casing, particularly in difficult formations, are critical.

Subsea BOP stacks are subject to additional problems:

Control lines extend a long distance from the actuating panels to the unit, increasing the chance of failure.

BOP systems operating under water are subject to very high hydrostatic pressure and a corrosive environment.

Large loads may be exerted on the BOP by the marine riser.

The marine riser is subjected to internal pressure from the mud and to flexural stresses from waves, current and vessel movement. Wear of the riser and loss of circulation through the wall can result if the rig is displaced laterally more than about seven percent of water depth. Forces and motions adversely affect the top and bottom ball joints and the slip joint. Other equipment such as the tensioning system and motion compensator are subject to failure and affect the safety and integrity of the drilling program.

In production, the wellhead flow control systems, safety valves and "christmas trees" pose safety problems. They are the centre of the subsea completion system and are subject to malfunction, leaks, corrosion and damage. Both wet and dry systems can have these problems and neither have been proven completely reliable under all circumstances.

In the Labrador Sea, iceberg scour is a hazard to the wellheads and pipelines. In the Arctic Islands ice scour from multi-year ice is a danger at shore approaches. Ice scour can occur in the Beaufort Sea but it is not a problem for the systems most likely to be used.

3.2.1.2.2 Production Platforms

Artificial earth islands intended for exploration drilling would require additional protection and maintenance for long-term use as production platforms. Wind, waves and ice would affect the islands continuously over the long period of use. Caisson islands would require frequent inspection and maintenance of their foundations.

Floating production platforms would most likely be dynamically positioned or quick release ships operating for a part of the year. Estimates of the operating season for such platforms in the Labrador Sea range from 100 days per year to 200-300 days per year with heavy icebreaker support. Such

platforms would require the ability to move off the site quickly if severe ice or icebergs interfered and to reposition and reconnect easily. The connections and disconnections hold great risks of error or malfunction and resulting fires, spills and pollution.

Some factors affect all platforms projecting above the water:

- 1) Extended use of the platform increases the probability that design safety factors would be exceeded in such terms as meeting hundred year storm forces or wave heights.
- 2) Corrosion increases with the age of the platform.
- 3) In areas prone to low visibility the probability of a ship collision increases.
- 4) Fuel sources may leak or vapours may escape and cause fires. In multi-well platforms it is extremely difficult to keep fire from spreading or to determine which wells are involved. Fire control planning and equipment must be provided to minimize the problem.

3.2.1.2.3 Well Servicing and Workover

After a well is drilled and production is begun there are numerous procedures which may be required to keep the well at maximum capacity throughout its producing life. These techniques which include acidizing, fracturing, cementing, perforating and others depend on the formations and the formation fluids encountered. The risks during these operations are high and environmental damage is possible if sufficient precautions are not taken.

3.2.1.3 Gathering Systems

The gathering system delivers crude oil from the field to the processing facilities. Principal components in the gathering system are the network of pipelines and the manifold.

Associated facilities include the following subsystems:

- . Pump Station Subsystem - a method of pumping and controlling the flow of crude oil during transfer through the gathering system.
- . Safety Subsystem - elements that provide methods of measuring and monitoring the gathering system to protect it from excessive or insufficient pressures, to detect leaks and combustible gases, and to provide for fire control and emergency shutdown.

The hazards involved in gathering systems include malfunctions, leaks, corrosion and damage, by ice scour. Ice scour is a particular concern at the shore approach of gathering pipelines.

3.2.1.4 Processing Systems

Development wells may produce oil, gas, condensates and formation waters in combination and they must be separated from the oil. The separation equipment may be located on a surface platform or onshore, depending on the quality of the produced fluid and the distance to shore.

For oil production the initial separation may be backed up by electrostatic treaters to meet specification requirements. Separated water must be treated and disposed of by dumping or reinjection.

Planning, design, quality control, supervision and maintenance are all required to ensure processing is not environmentally hazardous.

3.2.1.5 Storage Systems

If the oil is to be transported by tanker it may be stored in large tanks onshore or offshore. If pipelines are used, the oil may be pumped directly from the processing facilities. Spills and fires can result from accident and negligence, improper handling and collisions.

Offshore production requires the storage of waste as well as product.

3.2.1.6 Product Transfer Systems

In all areas of the study, there would be some form of oil transfer from storage facilities to transportation. In the Arctic Islands and the Beaufort Sea, this transfer would be from an onshore dock loading terminal to the tanker. In the Labrador Sea, the transfer is expected to be from floating storage alongside the ship.

Offshore product transfer involves the following hazards:

1. Umbilical lines from storage to ships, vulnerable to ice, wave and ship forces.
2. Subsea flowlines, vulnerable to ice scour, subsidence of poor bottom soils, corrosion and thermal stress.

3.2.2 Risk Assessment Methodology

The basic aim of risk assessment in this section is to highlight those parts of the production system that are the major causes of spills. To do this, the various hazards which lead to oil spills in the production system are considered. By combining the probabilities for a certain size spill for each individual hazard, the net probability of that size spill for the entire system can be calculated. By combining the results of spill size and hazard probability for each individual spill size, the relative importance of each hazard can be assessed.

Two tasks must be performed to carry out these computations:

Determine the hazards which can lead to a spill.

Evaluate spill probabilities associated with each one.

The hazard probabilities used in this study are derived from three sources:

Worldwide and Canadian statistics.

Previous analysis by other authors.

Probabilities calculated specifically for this study.

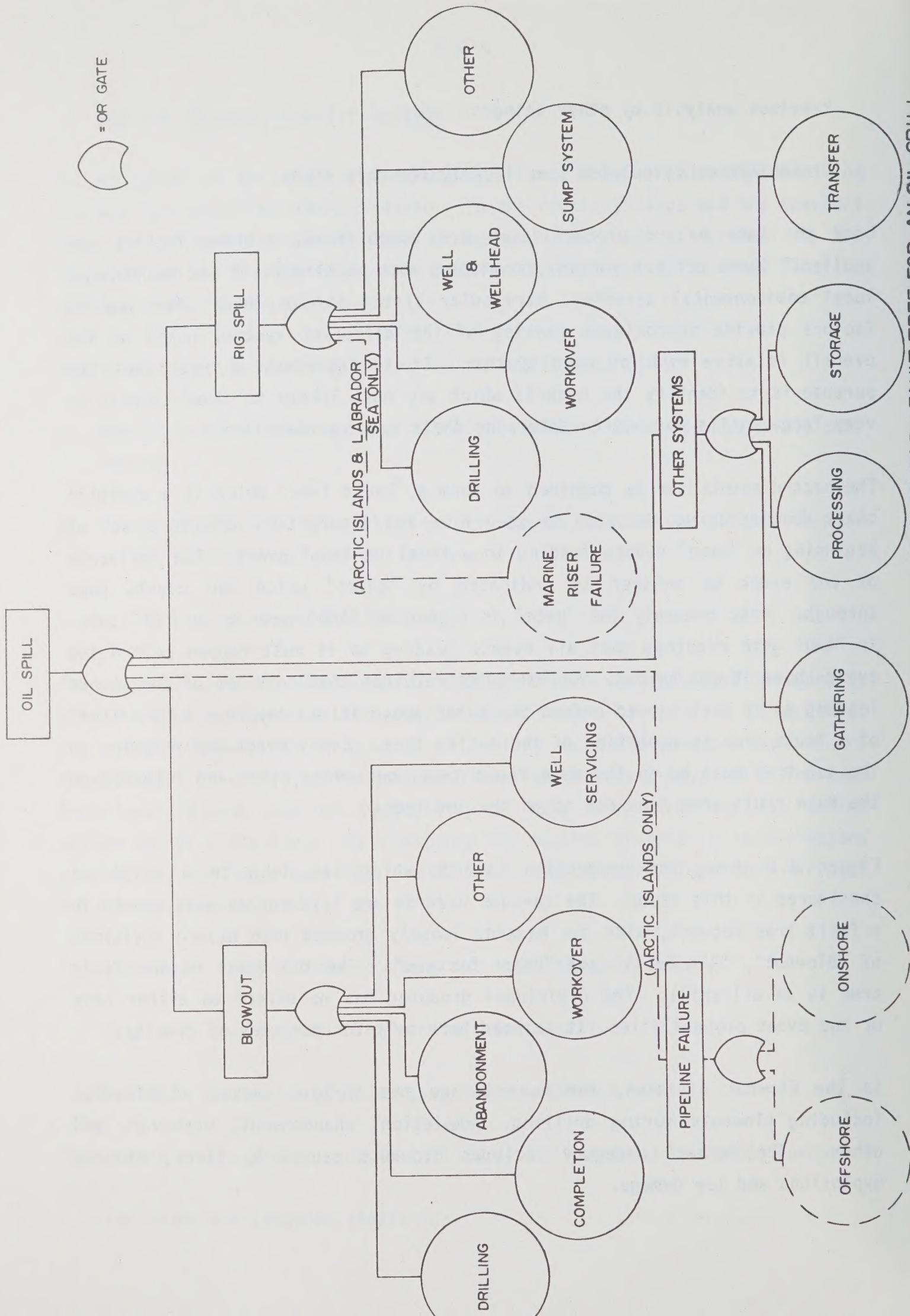
Once the base hazard probabilities are established, scaling factors are applied. These reflect various parameters such as effects of new technology, local environmental severity, particular system in use, etc. The scaling factors provide approximate ranking of the different systems based on the overall relative risk of each system. It is important to note that the purpose is to identify the hazards which are most likely to cause chronic or very large spills and not to determine their exact probabilities.

The hazard events can be combined to form a "Fault Tree" which is a symbolic chart demonstrating the step by step flow and interaction between a set of beginning or "base" events leading to a final or "top" event. The influence of one event on another is indicated by "gates" which the events pass through. Most commonly the "gate" is either an "AND" gate or an "OR" gate. An "AND" gate requires that all events leading to it must happen before the event above it may happen. An "OR" gate requires that only one of the events leading to it must happen before the event above it may happen. A "Sub-Tree" of a fault tree is a portion of the entire tree. Every event and relation on the sub-tree must be on the main fault tree, but every event and relation on the main fault tree need not be on the sub-tree.

Figure 3.1 shows the production hazards which can lead to a spill as considered in this study. The various hazards are laid out as base events in a fault tree network, with the hazards loosely grouped into hazard divisions of "Blowout", "Rig Spill" and "Other Systems". The top event of the fault tree is an oil spill. The divisional grouping has no effect on either base or top event probabilities, it is used here only for purposes of clarity.

In the Blowout division, the hazards are the various causes of blowouts including blowouts during drilling, completion, abandonment, workover, and other. The "other" category includes blowouts caused by fires, storms, explosions and ice damage.

OR GATE



ELEMENTARY FAULT TREE FOR AN OIL SPILL

The Rig Spill division includes spills during drilling (excluding blowout), spills during workover (excluding blowout) and spills associated with the well, wellhead, and sump system. Spills associated with the rig which do not fit into one of these categories are identified with the "other" category and include spills involving supply, disposal, etc.

The Other Systems division includes spills caused by the gathering system - which includes all pipes and flowlines on the rig; the processing system, including separation and treatment procedures; the storage system and the transfer system.

For the Arctic Islands, another division for Pipeline Failure is added. This includes spill hazards caused by onshore and offshore pipelines.

A description of the functions and possible problem areas for each of these hazards was given in Section 3.2.1. It should be noted here that each of the "Base" events shown on the tree could be considered as an intermediate event. An individual fault tree with more minor and basic events could be drawn which has as a "top" event one of the "base" events shown. As an example the base event "Blowout" during drilling was the top event and the subject of a complete study by Bercha (1971).

Three sub-trees have been developed to describe various phases of production. The phases are:

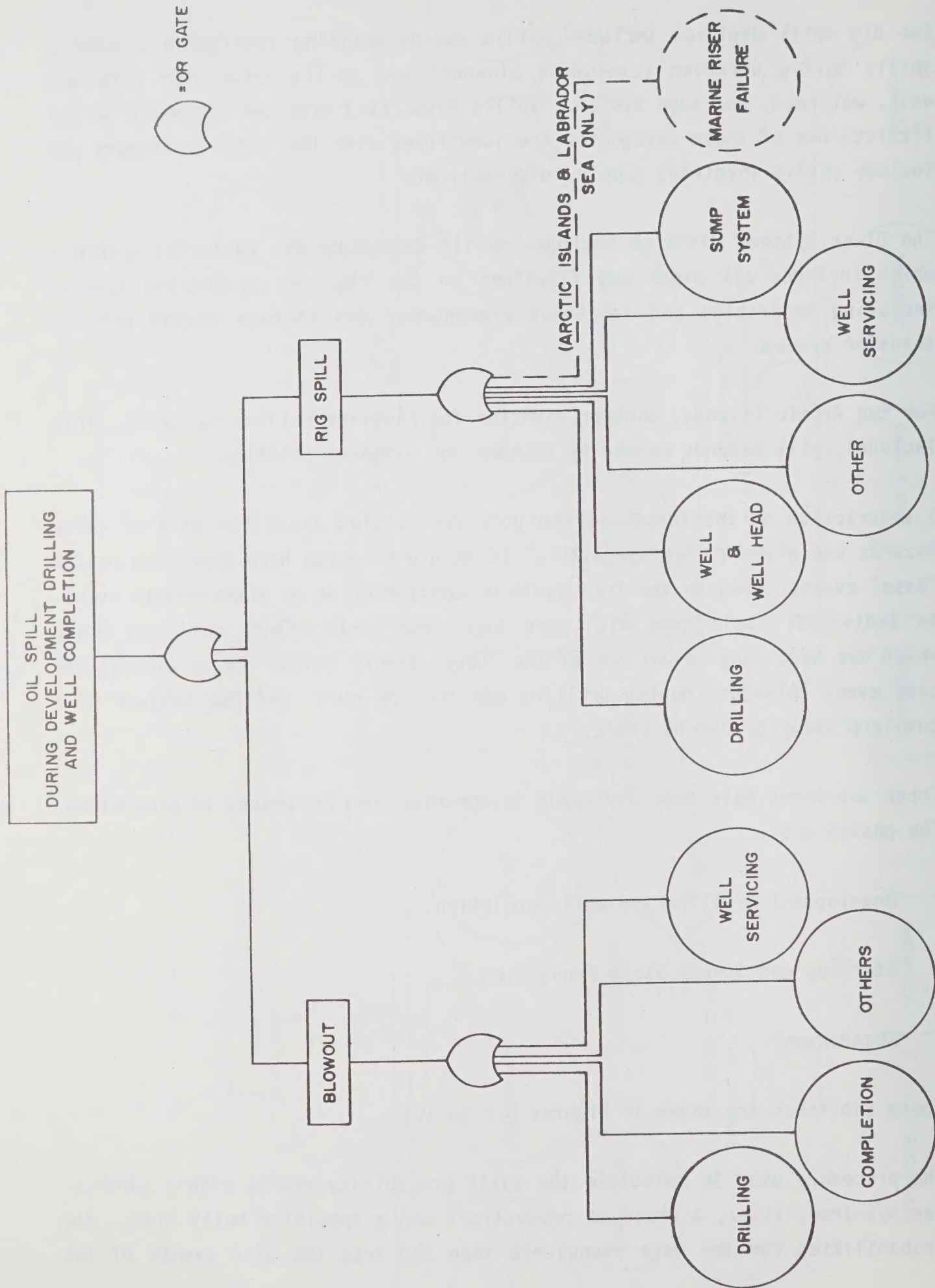
Development Drilling and Well Completion.

Start-Up and Steady State Production.

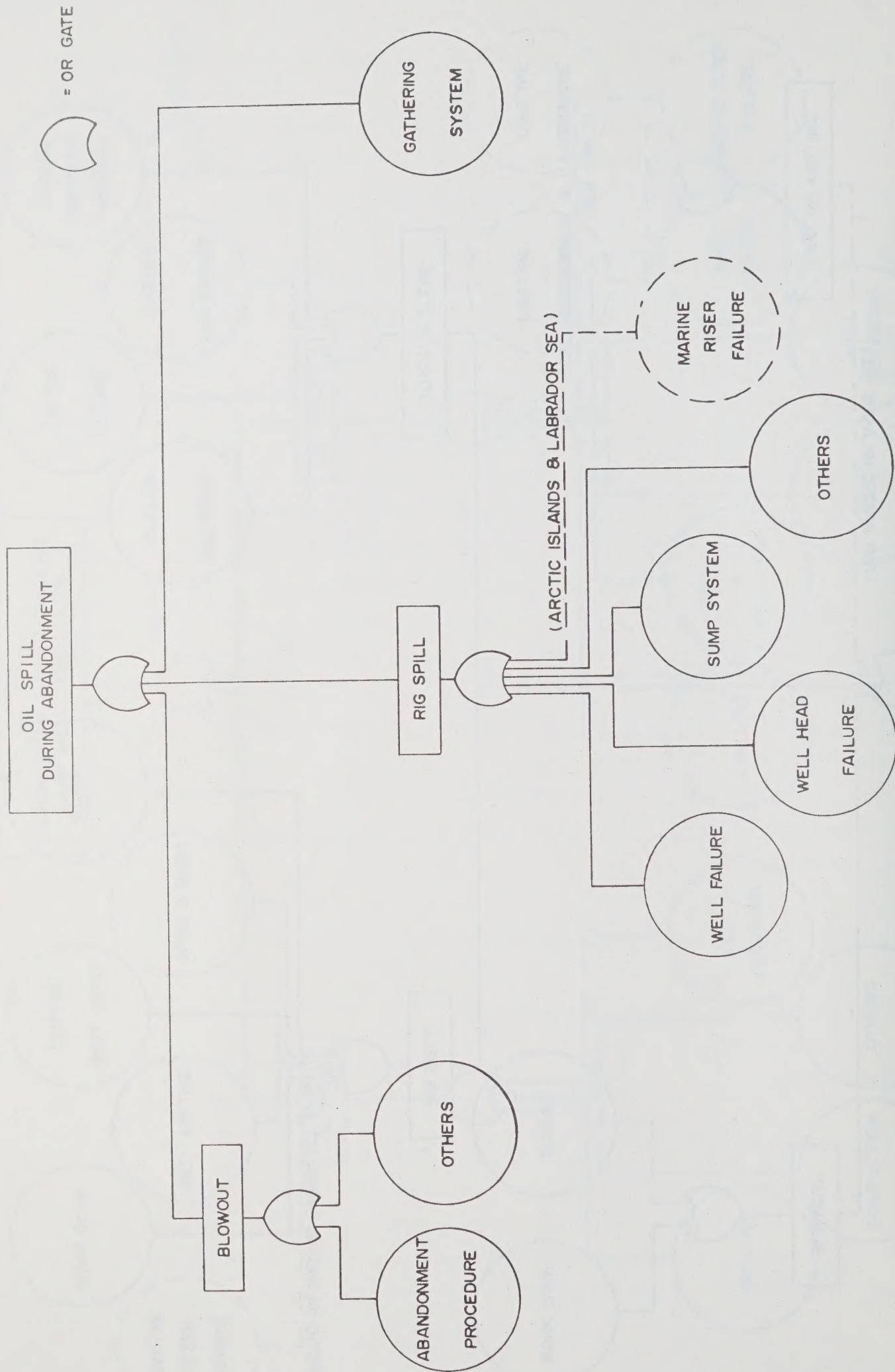
Abandonment.

These sub-trees are shown in Figures 3.2 to 3.4.

The procedure used to calculate the spill probability starts with a particular sub-tree, (i.e., a phase of production) and a specified spill size. The probabilities for the base events are then fed into the base events of the



ELEMENTARY FAULT TREE FOR OIL SPILL-DRILLING



ELEMENTARY FAULT TREE FOR OIL SPILL-ABANDONMENT
FIG 3.4

fault tree. From here two calculations can be performed. Since the fault tree is made up entirely of "OR" gates, a simple summation of all the probabilities will yield the expected number of spills of that size. Combining all the probabilities through logical "OR" relations will yield the probability of having at least one spill.

This procedure is repeated for each spill size and each phase of production, as well as for the different probabilities associated with the different regions.

3.2.3 Results of Analysis

3.2.3.1 General

The following section presents the results of estimates of base event probabilities. These numbers have been calculated from worldwide and Canadian statistics, estimates from other studies and estimates detailed here. No attempt has been made to produce highly precise probabilities for spills. An error factor of two to three was felt to be sufficiently accurate for the purposes of this study. Sources for the data used are indicated by reference numbers enclosed in brackets corresponding to a bibliography in Chapter 6.

All probabilities stated in the text are per well-year values unless labelled otherwise.

The sources of data used for this section cover oil spills in Canada, the United States, Europe and the North Sea. It is unusual to find data which are uniquely applicable to one of the systems proposed for the Canadian Arctic. Most sources list spills for only a vaguely defined system, at best differentiating between onshore and offshore spills.

To accommodate the different systems proposed for the Beaufort Sea Shallow and Deep water, Arctic Islands and Labrador Sea, scaling factors have been applied to the base probabilities. A scaling factor of one (1) is assumed if the system proposed appeared generally similar to the systems which the data

was taken. If the proposed system seems more hazardous, a scaling factor greater than one is used. Similarly, if the proposed system is less hazardous, a scaling factor less than one is used. The scaling factor serves to keep a ranking between the regions so that slightly safer systems within a region will result in a lower overall risk of spills for that region. The range of scaling factors for a particular system (i.e., the difference between the lowest and highest factors) is dependent on the following considerations:

The scope of detail in available data.

The difference in systems between regions.

Judgement in ranking system safety.

For this study we have broken down the range of potential spill sizes into classes, based on orders of magnitude. Each class is represented by a particular spill size. For example, the spill size 300 m^3 is used to represent the class $100\text{-}1000 \text{ m}^3$. The classes we have considered are related below to their representative size:

<u>Spill Size Class</u>	<u>Representative Size</u>
10-100 m^3	30 m^3
100-1000 m^3	300 m^3
1000-10,000 m^3	3000 m^3
10,000-100,000 m^3	30,000 m^3
100,000-1,000,000 m^3	300,000 m^3

All further reference to the size of spills is in terms of the representative spill size.

The phrase "maximum probable spill size" refers to a spill size value which is considered to be the largest possible spill size for a single hazard. Spills larger than the maximum probable spill size for a given hazard have

essentially zero probability. The following is a list of the hazards considered in this study and their maximum probable spill sizes.

<u>Hazard</u>	<u>Maximum Probable Spill Size</u>
Blowout	30,000 m ³
Production Spills	300 m ³
Storage, Processing and Transfer Spills	300 m ³
Pipeline Rupture (60 cm)	300 m ³
Largest Possible Pipeline Rupture	3,000 m ³
Tanker Spill (Ship Not Lost)	3,000 m ³
Tanker Loss	30,000 m ³

Notation - The logical "OR" relation is shown on Figures 3.1 to 3.4 as $\triangle$. In the text the "OR" relation is written as "v".

The probability of an event A, can be written as P(A). A group of n hazard probabilities will be identified with subscripts as $h_1, h_2, \dots, h_n$. E-notation will be used for probabilities on tables, where $nE_m = n \times 10^m$ or $4.1 E-2 = 4.1 \times 10^{-2} = .041$.

Formulae - The formulae used to calculate results in this section are given below.

$$1. \text{ Expected number of events} = \sum_{i=1}^n h_i$$

2. Combination through "OR" gate.

$$a. \text{ For two events} = h_1 v h_2 = h_1 + h_2 - (h_1 h_2).$$

$$b. \text{ For } n \text{ events with identical probabilities} = 1 - (1 - h_1)^n.$$

c. For n events with differing probabilities =

$$\sum_{j=1}^n (-1)^{j+1} \sum_{i_1 < i_2 < \dots < i_j} \left(\prod_{k=1}^j h_{i_k} \right)$$

where

$$\prod_{k=1}^j h_{i_k} = h_{i_1} \times h_{i_2} \times \dots \times h_{i_j}$$

3. Combination through "AND" relation, for n events = $h_1 \times h_2, \dots, h_n$

$$= \prod_{i=1}^n h_i$$

4. Meantime between failure (MTBF) = $(-\ln(1 - h))^{-1}$.

3.2.3.2 Blowouts

Blowouts releasing oil are uncommon, and those releasing oil offshore even more uncommon. Because of this, present historical data does not warrant a detailed breakdown by spill size and initial cause. Such division would certainly lack statistical significance. Instead, this section relies mainly on the work of Bercha (1978) and treats the risk of blowout with regard to the exploration phase of production. Scaling factors have been applied to accommodate the various production phases, drilling (completion, abandonment, etc.) which are felt to have different risks.

Blowouts are a major concern to the operators of rigs. A single blowout, though it may result in no oil spilled, can completely destroy a platform worth millions of dollars, and kill or injure many of the people working on

it. For these reasons, operators make every effort to keep blowout risk to a minimum. Operators attempt to have the finest technology available on the rig. Research and development programs are constantly improving the safety of drilling and production procedures.

Blowouts are not a major cause of oil spills. This is for two reasons:

Most blowouts are gas blowouts and do not release significant amounts of oil (90% [FENCO, July 1980]; 75% [Moser, 1976]).

Most blowouts "bridge" themselves or are controlled in a very short period of time (82% in < 10 days [Moser, 1976]) and therefore are only able to release a small amount of oil.

Combined with the low probability of a blowout at all (about 0.4% [Danenburger, 1980]), this makes the probability of a large oil spilling blowout very low, per well drilled.

The probability of a blowout must be considered in each phase of the life of a well:

During development drilling the geological formations are known, and through most of the operation there is no contact with the oil reservoir. This lowers the oil spill probability.

During production, the probability of an oil spill is higher, as contact is made with the reservoir.

Completion and workover are thought to be hazardous phases due to the complexity of the procedures and the resulting increase in the number of things that can go wrong.

Abandonment of the well at the end of its producing life is a safe procedure. However, the procedure can be as dangerous as workover if the abandonment is the result of an emergency.

Oil spills induced by blowouts, particularly during drilling, are an almost negligible risk compared with other spill sources. Unfortunately there have been two spectacular exceptions which detract from this conclusion:

In 1977, the Ekofisk Bravo well after two years of production blew out in the North Sea during a workover releasing approximately 26,000 m³ of oil.

In 1979 during development drilling the Ixtoc I well blew out in the Gulf of Mexico releasing (ultimately) approximately 450,000 m³ of oil. This spill is the largest offshore spill ever recorded which would appear to make blowouts one of the most significant causes of oil spills.

During the years 1971-78 in the Gulf of Mexico some 7500 wells were started. From these wells there were 46 blowouts, four resulting in oil spills [7]. One spill occurred during completion procedure ($< 3 \text{ m}^3$), one during workover (30 m^3), one from an explosion (70 m^3) and one from a storm (10 m^3). In all, less than 120 m^3 of oil were spilled, while production amounted to $450 \times 10^6 \text{ m}^3$, a spillage rate of less than 0.00003%.

The data as described are summarized in Table 3.1.

It is difficult, considering the state these statistics are in, to project them to such frontier areas as the Canadian Arctic and to make predictions for future spills. Historical data shows no trends in either the phase, the spill size or the cause of such incidents. Bercha (1978) has attempted to calculate these risks during exploratory drilling in the Beaufort Sea using fault tree analysis. This seems to be a practical way of estimating these risks. The results of Bercha's analysis are shown in Table 3.2.

Using Tables 3.1 and 3.2, blowout induced oil spill expectancy can be estimated. The results of the fault tree analysis for exploratory drilling are taken as base probabilities. A scaling factor appropriate to each phase is then multiplied onto that base probability. The scaling factors used are as follows:

TABLE 3.1

Number of Blow-outs Recorded, Gulf of Mexico and North Sea 1971-79

Phase or Operation	<u>Spill Size m³</u>						
	0	3	3E1	3E2	3E3	3E4	3E5
Exploration	21	0	0	0	0	0	0
Development Drilling	14	0	0	0	0	0	1
Completion	2	1	0	0	0	0	0
Workover	6	1	1	0	0	1	0
Abandonment	0	0	0	0	0	0	0
Other	8	0	2	0	0	0	0

TABLE 3.2

BLOWOUT EVENT PROBABILITIES WITH UPPER AND LOWER
BOUNDS FOR BEAUFORT SEA ARTIFICIAL ISLAND
(FROM BERCHA 1971)

Probability of Event Per Well Per Season

Type of Blowout Event	Significance	Normal		Diapir	
		Summer	Winter	Summer	Winter
(1)	Upper	0.818E-3	0.924E-3	2.82E-3	3.18E-3
Blowout	Mean	0.435E-3	0.492E-3	1.57E-3	1.77E-3
(Any Kind)	Lower	0.180E-3	0.204E-3	0.679E-3	0.768E-3
(2)	Upper	1.23E-4	1.39E-4	4.23E-4	4.77E-4
Blowout	Mean	0.544E-4	0.615E-4	1.96E-4	2.21E-4
(Q 50 bbl/day)	Lower	0.180E-4	0.204E-4	0.679E-4	0.768E-4
(3)	Upper	3.07E-5	3.47E-5	16.9E-5	19.1E-5
Blowout	Mean	1.09E-5	1.23E-5	6.46E-5	7.31E-5
(Q 500 bbl/day)	Lower	0.270E-5	0.306E-5	1.70E-5	1.92E-5
(4)	Upper	1.69E-6	1.91E-6	9.30E-6	10.5E-6
Blowout	Mean	0.544E-6	0.615E-6	3.23E-6	3.65E-6
(Q 5000 bbl/day)	Lower	0.122E-6	0.138E-6	0.764E-6	0.864E-6

	Beaufort Sea Shallow	Beaufort Sea Deep	Arctic Islands	Labrador Sea
Development Drilling	0.75	0.75	1.0	1.1
Completion	1.0	1.0	1.0	1.0
Workover	1.25	1.25	1.25	1.25
Abandonment	1.2	1.2	1.25	1.25
Other	1.25	1.25	1.0	1.25

The scaling factors for the Arctic Islands and Labrador Sea are higher during development drilling due to the need for a marine riser in both systems to keep the production platform remote from the well. Labrador Sea systems are also expected to be more at the mercy of environmental conditions and therefore have a greater possibility of being unable to control a kick.

No significant advantage or disadvantage is seen in any of the proposed regions for completion or workover procedures. For all systems, completion is estimated to have about the same risk as exploratory drilling, and workover to have a slightly higher risk.

Abandonment at the end of the life of a producing well is felt to have negligible risk of an oil spilling blowout. However, abandonment due to an emergency can lead to a blowout. In both the Beaufort Sea production schemes, the possibility of an emergency abandonment seems very low. Causes of an abandonment in the Beaufort Sea could include slope failure in the dredged island foundations or severe ice ride-up over the island. On this basis, a scaling factor of 1.2 has been used.

In both the Arctic Islands and the Labrador Sea proposed production systems the well must be abandoned yearly during drilling. Once production has started, the wells will produce year-round. The risks associated with abandonment are thought to be slightly higher in these areas due to the presence of the marine riser and the offshore location. The time spent in

abandonment procedures will be substantially higher because of the required disconnects. A scaling factor of 1.25 has been used.

Other causes for blowouts include fires, explosions, storms and ice damage. Production in the Beaufort Sea Shallow or Deep water systems is thought to be comparable to conventional systems. A scaling factor of 1.25 is used to account for "other causes" resulting in more oil spills than in exploratory drilling.

Once production is started in the Arctic Islands there will be a subsea wellhead connected to shore by an underwater pipeline. Having the entire installation underwater should give the Arctic Islands production system some degree of isolation from environmental hazards and a scaling factor of 1.0 has been used in this region.

In the Labrador Sea the scenario is also based on a subsea completion, again shielded from environmental hazards. In this region, there are additional risks from icebergs drifting south from Davis Strait. This possibility of an iceberg hitting the rig or scouring the seabed and destroying the wellhead has been considered for the Labrador Sea. It has been concluded that the Labrador Sea system is more hazardous than either of the Beaufort Sea systems. The same scaling factor of 1.25 has been used.

The possibility of an iceberg hitting a rig in the Labrador Sea is fairly high. The calculation of such an event is difficult as iceberg densities vary with latitude and distance from the coast. An average probability, however, can be calculated by averaging the probabilities of iceberg threat per well per 1° grid per season, using the average number of icebergs per 1° grid per season and the location of existing or past wells. This probability will be equal to the average P (iceberg threat) for the future wells in the Labrador Sea. The probability of contact designated $P(\theta)$ between an iceberg with an approach angle θ and a platform of size s in a rectangle size $E \times S$ where E is the width of one degree latitude and S the width of one degree longitude for the geographical area under study can be expressed as follows [3]:

$$P(\theta) = \frac{i + s}{W}$$

where i is the width of the iceberg and where W is the width of the rectangle normal to the iceberg path. From geometry,

$$W = E \cos \theta + S \sin \theta$$

If it is assumed that all approach angles are equally likely, $P(A)$, the probability averaged over all possible values of θ can be expressed as:

$$P(A) = \int_0^{2\pi} \frac{(i + s)}{W} d\theta$$

performing the integration:

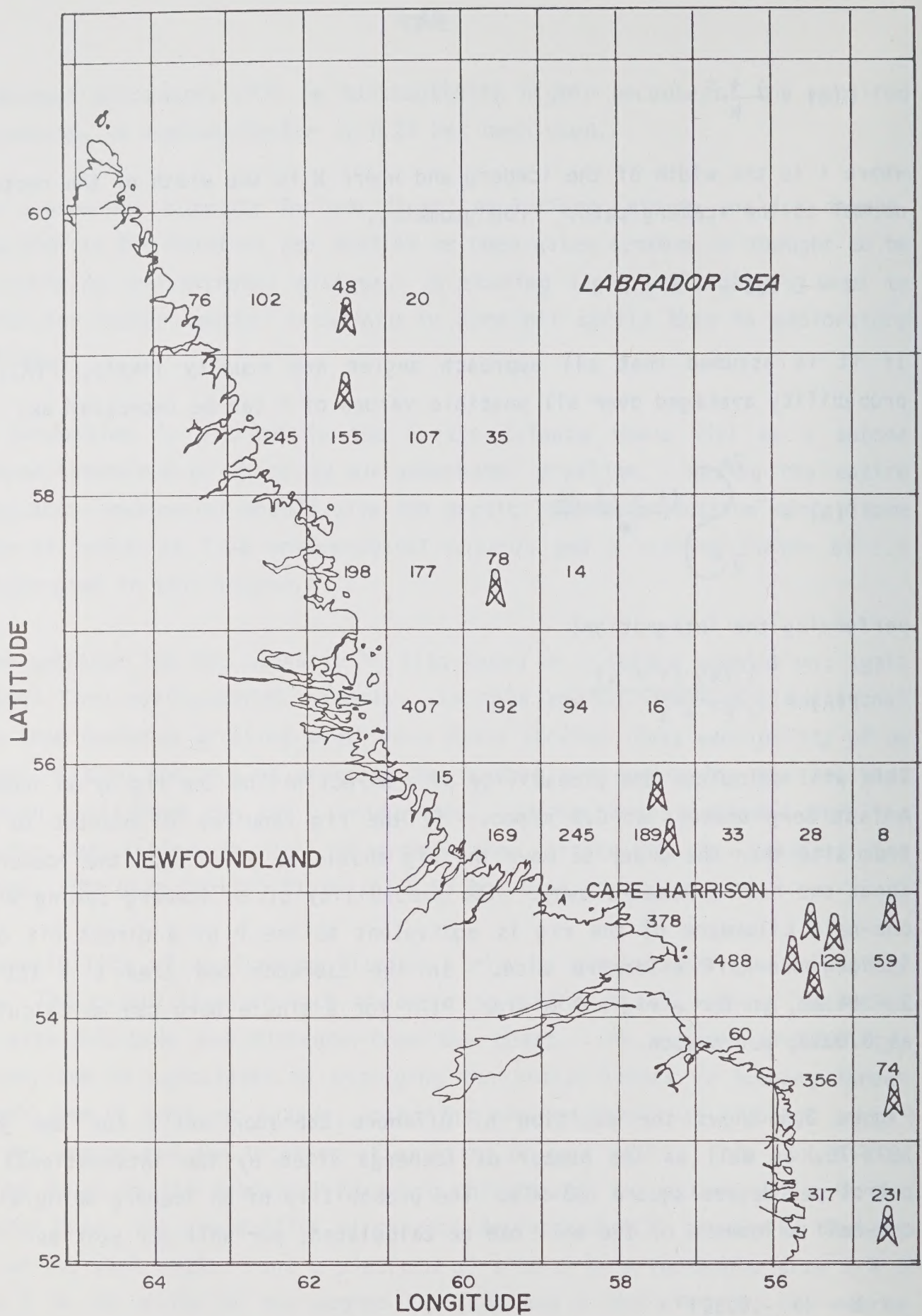
$$P(A) = \frac{1.149 (i + s)}{\sqrt{E^2 + S^2}}$$

This will calculate the probability of a direct hit on the rig by an iceberg. A fast berg travels at 0.5 m/sec. If the rig requires 10 minutes to move from site then the order to move the rig should be given when the iceberg is about one-half kilometre away. The probability of an iceberg coming within one-half kilometre of the rig is equivalent to the P of a direct hit of an iceberg one-half kilometre wide. In the Labrador Sea area $E = 111$ km, $S = 64$ km, so for a rig 150 m wide, $P(A)$ for a single berg can be calculated as 0.0059, per season.

Figure 3.5 shows the position of offshore Labrador wells for the years 1971-76, as well as the number of icebergs sighted by the international ice patrol per degree square (63-67). The probability of an iceberg being within one-half kilometre of the well can be calculated, per well per year as:

$$1 - (1 - .0059)^n$$

where n = the number of icebergs expected in the one degree square per year.



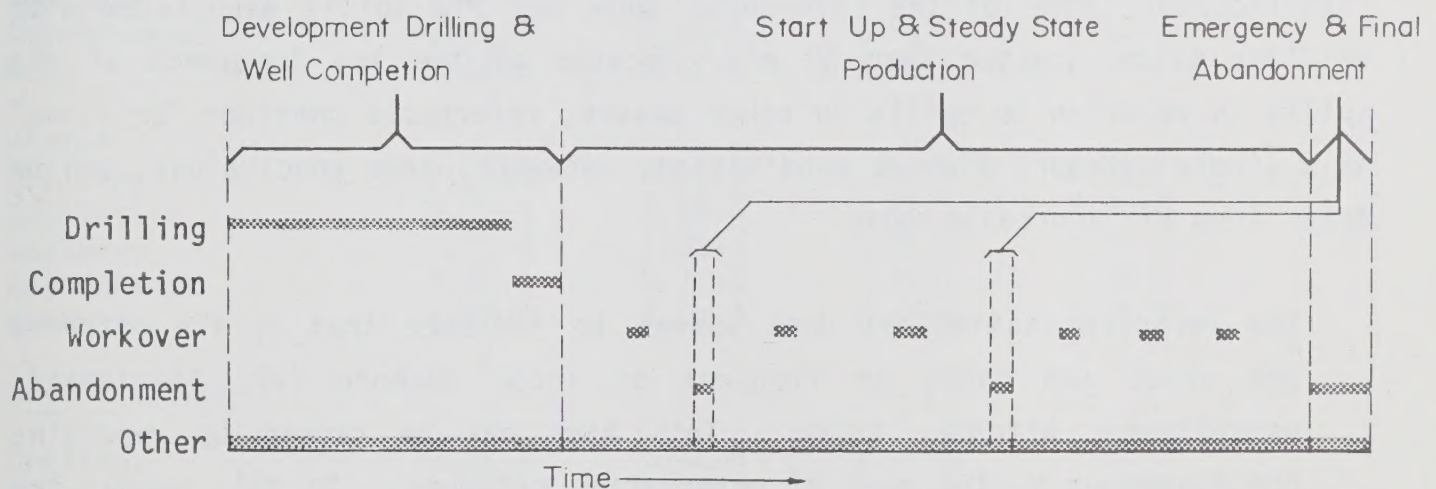
NUMBER OF ICEBERGS SIGHTED BY THE INTERNATIONAL ICE PATROL
PER DEGREE SQUARE & WELL LOCATIONS IN LABRADOR SEA

This figure, averaged for all wells shown in Figure 3.5 gives a probability that an iceberg will come within one-half kilometre of a drill site and a disconnect will be required equal to 0.56 per well per year.

To determine spill sizes for the purposes of this study, Bercha's analysis has been used. The analysis considers that any significant blowout will flow for a period of two months. This assumes that environmental conditions might hinder capping or relief well drilling operations, or that a relief well might not be successful.

The results of applying scaling factors for each phase and region to Bercha's results are shown in Table 3.3 for flow rates in the order of 30, 300, 3,000 or 30,000 m³ of oil.

The numbers calculated cannot be used immediately to calculate a total blowout probability through the fault trees in Figures 3.2 to 3.4 as the hazards are not independent. Workover, development drilling, completion and abandonment all occur discretely with no time overlap between them. This is shown graphically as follows:



A solid line indicates that the particular hazard is present. An estimate of the percentage of time involved for each hazard in each phase is multiplied onto the probability to account for the dependency of the hazards. After this, the overall probabilities of blowouts in each phase can be calculated. The time percentages which have been assumed are summarized as follows:

Development Drilling (DD)	85%
Completion (CO)	15%
Workover (WO)	10%
Abandonment (AB)	100%
Other (OT)	100%

These percentage values are used to develop probabilities for the various spill sizes in the selected regions. These are summarized in Tables 3.9 to 3.22 for each phase of development and each cause of blowout.

3.2.3.3 Development Drilling and Well Completion

Rig Spills

Rig spills are uncommon during drilling. They represent about one percent of the number of spills reported and about one percent of the volume of spills. This seems appropriate considering the short period of drilling compared to the producing life of the well. The areas where they may occur are shown on Figures 3.2 under "Rig Spill". Because of their infrequent occurrence, the data for appreciably sized rig spills during drilling lack any statistical significance. None of the references show any rig spills associated with drilling to be greater than 30 m³. Because of the low frequency of rig spills in relation to spills in other phases, references consider "Drilling" as a single category without subdivision. However, some conclusions, can be drawn from the available data:

The recorded statistical data appear to indicate that spills offshore are about ten times as frequent as those onshore (API Statistics, unpublished; Ritchie, 1973). This bias may be caused by reporting procedures or by the ease of observation offshore. In this study, the recorded data has been used without arbitrary adjustment. On this basis, the Beaufort Sea Shallow and Deep systems are assumed to have one-tenth the number of spills that the Labrador Sea and Arctic Islands have (Ritchie, 1973).

Because the percentage of number of spills associated with drilling is consistent with the percentage of volume of spills associated with

TABLE 3.3

ESTIMATED BLOWOUT PROBABILITIES FOR ALL REGIONS AND PHASES
PER WELL PER YEAR (SEASON)

Region and Place	Spill Size m ³			
	30	300	3000	30,000
<u>Beaufort Sea Shallow</u>				
Summer				
Drilling	6.5E-4	5.4E-5	1.4E-5	6.6E-7
Completion	8.6E-4	7.2E-5	1.8E-5	8.8E-7
Workover	1.1E-3	9.0E-5	2.3E-5	1.1E-6
Abandonment	1.0E-3	8.6E-5	2.2E-5	1.1E-6
Other	1.1E-3	9.0E-5	2.3E-5	1.1E-6
Winter				
Drilling	7.3E-4	6.1E-5	1.5E-5	7.4E-7
Completion	9.7E-4	8.1E-5	2.0E-5	9.9E-7
Workover	1.2E-3	1.0E-4	2.5E-5	1.2E-6
Abandonment	1.2E-3	9.7E-5	2.4E-5	1.2E-6
Other	1.2E-3	1.0E-4	2.5E-5	1.2E-6
<u>Beaufort Sea Deep</u>				
Summer				
Drilling	6.5E-4	5.4E-5	1.4E-5	6.6E-7
Completion	8.6E-4	7.2E-5	1.8E-5	8.8E-7
Workover	1.1E-3	9.0E-5	2.3E-5	1.1E-6
Abandonment	1.0E-3	8.6E-5	2.2E-5	1.1E-6
Other	1.1E-3	9.0E-5	2.3E-5	1.1E-6
Winter				
Drilling	7.3E-4	6.1E-5	1.5E-5	7.4E-7
Completion	9.7E-4	8.1E-5	2.0E-5	9.9E-7
Workover	1.2E-3	1.0E-4	2.5E-5	1.2E-6
Abandonment	1.2E-3	9.7E-5	2.4E-5	1.2E-6
Other	1.2E-3	1.0E-4	2.5E-5	1.2E-6
<u>Arctic Islands</u>				
Drilling	8.8E-4	6.4E-5	1.6E-5	7.8E-7
Completion	8.8E-4	6.4E-5	1.6E-5	7.8E-7
Workover	1.1E-3	8.0E-5	2.0E-5	9.8E-7
Abandonment	1.1E-3	8.0E-5	2.0E-5	9.8E-7
Other	8.8E-4	6.4E-5	1.6E-5	7.8E-7
<u>Labrador Sea</u>				
Drilling	9.8E-4	7.0E-5	1.8E-5	8.6E-7
Completion	8.8E-4	6.4E-5	1.6E-5	7.8E-7
Workover	1.1E-3	8.0E-5	2.0E-5	9.8E-7
Abandonment	1.1E-3	8.0E-5	2.0E-5	9.8E-7
Other	1.1E-3	8.0E-5	2.0E-5	9.8E-7

drilling, it will be assumed here that no operation of drilling is particularly more hazardous than identical operations during production. With this in mind, the subdivision of rig spills as outlined in the following Start-Up and Steady State Production section is also used for rig spills during drilling.

An estimate for the effect of the marine riser on the Arctic Islands and Labrador Sea drilling systems is made. It is estimated that the riser will add about ten percent to the well risk. The ten percent factor is used to ensure ranking of the risks, with the Beaufort Sea systems having slightly lower risks.

Table 3.4 presents the results of this analysis as a summary of the probability of rig spills by size and region in the drilling phase.

3.2.3.4 Start-Up and Steady State Production

Rig Spills

Rig spills in start-up and steady state production are considered to originate from the sources shown in Figure 3.3. These sources are listed as follows; sump system, workover, marine riser, well, wellhead and other.

In the start-up and steady state production phase, records indicate a large number of very small spills, 0.2 m^3 (one barrel) or less. These small spills are distributed throughout the various systems. Spills from leaking valves, overflowing tanks, corroded pipes, etc., account for a majority in the number of spills but only a small percentage of the volume. Between 1971 and 1975, nearly 6000 spills were reported in the Gulf of Mexico. Of these, 99.5 percent were less than 10 m^3 (60 barrels) and they accounted for less than ten percent of the total volume spilled. In the start-up and steady state production phase, data show offshore rigs have about twice as many spills as onshore rigs for well and wellhead spills. Offshore rigs have about ten times as many sump spills.

TABLE 3.4

PROBABILITY OF RIG SPILLS BY SIZE AND REGION - DRILLING
EACH WELL PER YEAR

SPILL SIZE AND REGION	3				30			
	BS	BD	AI	LS	BS	BD	AI	LS
Well	2.8E-5	2.8E-5	2.4E-4	2.4E-4	-	-	-	-
Wellhead	8.8E-5	8.8E-5	7.4E-4	7.4E-4	-	-	-	-
Sump System	1.5E-4	1.5E-4	1.3E-3	1.3E-3	-	-	-	-
Marine Riser	NA	NA	2.4E-5	2.4E-5	-	-	-	-
Drilling & Other	2.1E-4	2.1E-4	1.8E-3	1.8E-3	5.0E-5	5.0E-5	4.4E-4	4.4E-4

Legend BS = Beaufort Sea (Shallow)

BD = Beaufort Sea (Deep)

AI = Arctic Islands

LS = Labrador Sea

The available statistical data references do not identify the marine riser as a specific origin of spills. In developing probabilities for the purposes of this study, marine riser spills are included with well spills.

Table 3.5 presents the results of this analysis as a summary of the probability of rig spills by size and region in start-up and steady state production.

Other Systems

The gathering system considered here includes the network of pipes and flowlines on the rig itself. Each region is expected to use a similar gathering system. The data used (Ritchie, 1973; Danenburger, Circular 741) show about the same probability of spill for both onshore and offshore wells. For spills of 3 m^3 the probability is about $2.3\text{E}-2$, for 30 m^3 it is about $1.0\text{E}-3$. No spills are reported greater than 30 m^3 .

The storage systems are slightly different in each of the regions. The Beaufort Sea systems will have storage tanks on the artificial islands. In the Arctic Islands, storage will be on land, connected to a subsea well completion by pipeline. In the Labrador Sea, storage will be on floating vessels.

The data used to estimate storage system spills include those spills resulting from tanks and tank associated equipment (firewalls, supporting structures, etc.). The basic accident rate for offshore spills shows a probability of $8.2\text{E}-3$ for spills of 3 m^3 , $6.7\text{E}-4$ for spills of 30 m^3 , no spills reported of 300 m^3 and $2.0\text{E}-4$ for $3,000 \text{ m}^3$ (API Statistics, Unpublished; Danenburger, Circular 741; Ritchie, 1973).

To account for the different systems, scaling factors appropriate to each system have been applied to the data as follows:

Beaufort Sea Shallow	- 1.0
Beaufort Sea Deep	- 1.2
Arctic Islands	- 0.5
Labrador Sea	- 1.5

TABLE 3.5

PROBABILITY OF RIG SPILLS BY SIZE AND REGION - PRODUCTION
EACH WELL PER YEAR

SPILL SIZE AND REGION	3 m ³				30 m ³			
	BS	BD	AI	LS	BS	BD	AI	LS
Sump System	1.7E-3	1.7E-3	1.7E-2	1.7E-2	1.0E-4	1.0E-4	1.0E-3	1.0E-3
Work over	5.2E-4	5.2E-4	1.0E-3	1.0E-3	-	-	-	-
Well	1.1E-3	1.1E-3	2.2E-3	2.2E-3	-	-	-	-
Well Head	3.3E-3	3.3E-3	6.7E-3	6.7E-3	-	-	-	-
Other	1.1E-2	1.1E-2	2.3E-2	2.3E-2	5.2E-4	5.2E-4	1.0E-3	1.0E-3

Legend BS = Beaufort Sea (Shallow)

BD = Beaufort Sea (Deep)

AI = Arctic Islands

LS = Labrador Sea

The processing systems in each region include the separation and treatment of the oil. The systems are essentially the same in each region. However, available data indicate that onshore operations have about a third as many spills as offshore (API Statistics, Unpublished; Ritchie, 1973). No spills of greater than 30 m³ are documented. The Beaufort Sea systems are assumed to perform essentially as onshore facilities.

The transfer systems in each region differ significantly. In the deep water Beaufort Sea, transfer will take place within the protective atoll. In the Beaufort Sea shallow region, transfer will be from storage tanks on the artificial islands to tankers moored off the island. In the Arctic Islands, a port located at Allison Inlet on the south shore of Bathurst Island will transfer oil to tankers. In the Labrador Sea, transfer will be directly from floating storage to tankers.

Typically, transfer spills have been expressed as a percentage of volume of oil handled. The oil spilled percentages reported range from 0.00004 percent to 0.01 percent (Oceanographic Institute, 1972), although more recent studies show that the amount of oil spilled in port is between 0.004 and 0.007 percent. Using the more recent data would indicate that 40 to 70 m³ of oil are spilled in port for every one million m³ handled. Much of this oil spilled is due to transfer. Most of the spills involved with transfer are very small, usually less than 3 m³ and seldom as large as 30 m³. However, the number of spills is very large. To estimate the probability of transfer spills under Arctic conditions, fault trees have been created for spill sizes of 3, 30 and 300 m³ (Welker, 1976). The probabilities estimated from the fault trees are 5E-2, 7E-3 and 2E-7 respectively. In this case, the probability is represented as probability per port call. To account for the different systems in each region, scaling factors are applied to the transfer probabilities to best reflect the safest systems. The scaling factors used are:

Beaufort Sea Shallow	- 1.5
Beaufort Sea Deep	- 1.2
Arctic Islands	- 1.0
Labrador Sea	- 1.3

The values shown in Table 3.6 use the fault tree results and these scaling factors.

Pipeline

A fairly short pipeline is envisioned as a link between the Arctic Islands production system and the Arctic Islands transportation system.

The pipeline considered would connect to the subsea wellhead of the Arctic Islands production system, from which it would traverse the sea bed to the nearest island, in this study this would be Bathurst Island. From this point the pipeline would cross the island to a tanker port at Allison Inlet. In all, it is thought that the pipeline would be about 250 km in length of which 50 km would be offshore and 200 km onshore.

Historically, pipelines have had an extremely high spillage rate, accounting for nearly 50% of reported spills (Ritchie, 1973). Single pipeline spills can be very large, for example, the Bonita pipeline break spilled 3000 m³. Statistics for large offshore pipeline spills show that total spill volume is equal to 0.011% of the volume handled (Booz-Allen and Hamilton, 1975). This figure assumes that the volume of oil spilled is proportional to the volume of oil handled. Offshore pipelines statistics are not available for detailed information such as combined length of pipe, total flow through and individual spill sizes. To determine the probability of particular spill sizes from available data, it would be necessary to make the further assumption that the distribution of spill sizes is the same onshore and offshore.

The Oil Pipeline Subcommittee, Canadian Petroleum Association statistics (1980) for onshore pipeline spills give a detailed breakdown of spill sizes and causes. Using statistics from 1977-79, the number of spills of size "n" divided by the number of kilometres of pipeline would give the probability per kilometre per year of that spill size. The probability of a spill of magnitude "n" in a pipeline "k" kilometres long can then be calculated as:

$$1 - (1 - P(n))^k$$

TABLE 3.6

SYSTEM SPILL PROBABILITY BY SIZE AND REGION - PRODUCTION

SPILL SIZE AND REGION

Cause	3				30				300				3000			
	BS	BD	AI	LS	BS	BD	AI	LS	BS	BD	AI	LS	BS	BD	AI	LS
Gathering	2.5E-2	2.5E-2	2.3E-2	2.3E-2	1.0E-3	1.0E-3	1.0E-3	1.0E-3	-	-	-	-	-	-	-	-
Storage	8.2E-3	9.8E-3	4.1E-3	1.2E-2	6.7E-4	8.0E-4	3.4E-4	1.0E-3	3.7E-4	4.4E-4	1.9E-4	5.5E-4	2.0E-4	2.4E-4	1.0E-4	3.0E-4
Processing	1.1E-2	1.1E-2	3.7E-2	3.7E-2	1.2E-3	1.2E-3	3.6E-3	3.6E-3	-	-	-	-	-	-	-	-
Transfer	7.5E-2	6.0E-2	5.0E-2	6.5E-2	1.1E-2	8.4E-3	7.0E-3	9.1E-3	3.4E-7	2.7E-7	2.3E-7	2.9E-7	-	-	-	-
Total	1.1E-1	1.0E-1	1.1E-1	1.2E-1	1.4E-2	1.1E-2	1.2E-2	1.5E-2	3.7E-4	4.4E-4	1.9E-4	5.5E-4	2.0E-4	2.4E-4	1.0E-4	3.0E-4

Legend BS = Beaufort Sea (Shallow)
 BD = Beaufort Sea (Deep)
 AI = Arctic Islands
 LS = Labrador Sea

Probabilities:

- . Gathering, storage and processing each well, per year.
- . Transfer, each vessel, per port of call.

Considering both assumptions:

Oil spilled is directly proportional to oil handled.

Distribution of spill sizes is the same onshore and offshore.

It can be estimated that:

$$\frac{\frac{\text{bbl spilled}}{\text{bbl handled}} \text{ onshore}}{\frac{\text{bbl spilled}}{\text{bbl handled}} \text{ offshore}} = \frac{P(n) \text{ onshore}}{P(n) \text{ offshore}}$$

where $P(n)$ is the probability of a spill of magnitude "n" per kilometre of pipeline per year.

The probabilities shown in Table 3.7 use these assumptions and the CPA statistics. The probabilities are estimated for the total length of the line, 50 km for the offshore pipeline and 200 km for the onshore pipeline.

3.2.3.5 Abandonment

Rig Spills - Spill risk during a normal abandonment can be presumed to be less than or equal to the spill risk during steady state production. The risks considered here are those associated with a forced or emergency abandonment.

None of the data sources used list abandonment as a specific cause of spills. It can be anticipated, however, that for the proposed production schemes in the Canadian Arctic the possibility of a forced abandonment is quite high (example, see section 3.2.3.2 regarding iceberg threat in the Labrador Sea) and the probability of a spill could be significantly increased.

In order to estimate the increase in spill risk, scaling factors are again used. The scaling factors are applied to the probabilities for rig spills during the start-up and steady state production phase as calculated in section 3.2.3.4. The factors used are:

TABLE 3.7

PIPELINE SPILL PROBABILITY * - ARCTIC ISLANDS

Location	<u>SPILL SIZE m³</u>			
	3	30	300	3000
Onshore (200 km)	1.2E-1	1.1E-1	3.6E-2	6.9E-3
Offshore (50 km)	1.3E-1	1.1E-1	3.8E-2	7.3E-3

* Probability is given in probability per year for Arctic pipeline route

	Beaufort Sea Shallow	Beaufort Sea Deep	Arctic Islands	Labrador Sea
Well Failure	1.05	1.05	1.1	1.1
Wellhead Failure	1.1	1.1	1.1	1.1
Sump System	1.0	1.0	1.0	1.0
Other	1.0	1.0	1.0	1.0

Marine riser failure is included with well failure.

During an emergency abandonment, human error may increase due to time limitations and procedures not normally implemented may cause higher than normal stresses in the various components of the well and wellhead.

Probabilities of oil spills by size and region in the abandonment phase are shown in Table 3.8.

Other Systems - Processing, storage and product transfer systems are not expected to be influenced by abandonment, and spill risk is considered the same as during start-up and steady state production.

The gathering system is considered to have a slightly higher risk in an emergency abandonment. A scaling factor of 1.1 is applied to the results from section 3.2.3.4 to represent these risks. The same scaling factor has been used for all regions. The results are shown in Table 3.8.

3.2.3.6 Combined Probability Tables

Tables 3.9 to 3.23 combine the probabilities shown in Tables 3.1 to 3.8 to produce the probability of a spill size for a particular production phase and a particular region. The formulae used are those shown in section 3.2.3.1.

Probabilities for the blowout division are combined as described in section 3.2.3.2 and then scaled to reflect the ratio of production in diapir and normal geological zones (Bercha, 1978). To determine the actual probability in

PROBABILITY OF OIL SPILLS - ABANDONMENT
PROBABILITY EACH WELL, EACH ABANDONMENT

Cause	SPILL SIZE m ³															
	3								30							
	BS	BD	AI	LS	BS	BD	AI	LS	BS	BD	AI	LS	BS	BD	AI	LS
Well	1.2E-3	1.2E-3	2.4E-3	2.4E-3	-	-	-	-	-	-	-	-	-	-	-	-
Wellhead	3.6E-3	3.6E-3	7.4E-3	7.4E-3	-	-	-	-	-	-	-	-	-	-	-	-
Sump	1.7E-3	1.7E-3	1.7E-2	1.7E-2	1.0E-4	1.0E-4	1.0E-3	1.0E-3	-	-	-	-	-	-	-	-
Other	1.1E-2	1.1E-2	2.3E-2	2.3E-2	5.2E-4	5.2E-4	1.0E-3	1.0E-3	-	-	-	-	-	-	-	-
Gathering	2.8E-2	2.8E-2	2.5E-2	2.5E-2	1.1E-3	1.1E-3	1.1E-3	1.1E-3	-	-	-	-	-	-	-	-
Storage	8.2E-3	9.8E-3	4.1E-3	1.2E-2	6.7E-4	8.0E-4	3.4E-4	1.0E-3	3.7E-4	4.4E-4	1.9E-4	5.5E-4	2.0E-4	2.4E-4	1.0E-4	3.0E-4
Processing	1.1E-2	1.1E-2	3.7E-2	3.7E-2	1.2E-3	1.2E-3	3.6E-3	3.6E-3	-	-	-	-	-	-	-	-
Transfer	7.5E-2	6.0E-2	5.0E-2	6.5E-2	1.1E-2	8.4E-3	7.0E-3	9.1E-3	3.4E-7	2.7E-7	2.3E-7	2.9E-7	-	-	-	-

Legend
BS = Beaufort Sea (Shallow)
BD = Beaufort Sea (Deep)
AI = Arctic Islands
LS = Labrador Sea

a diapir zone, the probabilities given in Tables 3.9 to 3.23 should be multiplied by 4. For a normal zone divide the probabilities by 1.2. The differing summer and winter probabilities are separately identified.

Table 3.24 shows the estimated probability of spills, from Tables 3.9 to 3.23, adjusted to the number of wells expected in each production region, i.e., Beaufort Sea Shallow - 10 wells, Beaufort Sea Deep - 20 wells, Arctic Islands - 10 wells, Labrador Sea - 10 wells. Also shown are the expected number of spills and the expected volume of oil spilled.

3.3 Reliability of the Transportation Systems

3.3.1 The Ship Transportation System

3.3.1.1 Ship Traffic Versus Region

For the purpose of the shipping system reliability analysis the study area has been divided into five zones which are assumed to have uniform risk within each region. The reliabilities are then estimated for each region as a whole. The regions are:

- Labrador Sea/Davis Strait
- Parry Channel - Port Region
- Lancaster Sound - Coastal Region
- Beaufort Sea - Port Region
- Beaufort Sea - Coastal Region

Within each of these regions, the navigated area has substantially uniform traffic density. Since all ship accident statistics are reported in terms of "port", "coastal" or "at sea" areas it is necessary to arrange the shipping lanes in regions which fit the assumptions of uniformity which are used in the statistical analyses.

Of the eight ships comprising the petroleum production shipping transportation system we have assumed that, at any instant, three of the petroleum production ships are operating in the Labrador Sea/Davis Strait region and

TABLE 3.9

PHASE-DEVELOPMENT DRILLING AND WELL COMPLETION SPILL SIZE - 3 m³

REGION	COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
	BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea Shallow	NE	4.8E-4	NA	NA	4.8E-4	2100
Beaufort Sea Deep	NE	4.8E-4	NA	NA	4.8E-4	2100
Arctic Islands	NE	4.1E-3	NA	NA	4.1E-3	240
Labrador Sea	NE	4.1E-3	NA	NA	4.1E-3	240

TABLE 3.10

PHASE-DEVELOPMENT DRILLING AND WELL COMPLETION, SPILL SIZE - 30 m³

REGION		COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea Shallow	w	2.0E-3				2.0E-3	490
	s	1.9E-3	5.0E-5	NA	NA	1.9E-3	510
Beaufort Sea Deep	w	2.0E-3				2.0E-3	490
	s	1.9E-3	5.0E-5	NA	NA	1.9E-3	510
Arctic Islands		1.7E-3	4.4E-4	NA	NA	2.1E-3	470
Labrador Sea		2.1E-3	4.4E-4	NA	NA	2.5E-3	390

Comments:

BO = Blowout
 RS = Rig Spill
 OS = Other System
 PL = Pipeline
 NE = Not Estimated

NA = Not Applicable
 - = Zero or Negligible
 w = Winter
 s = Summer

Note:

Probabilities per well per year (or per season).

TABLE 3.11

PHASE-DEVELOPMENT DRILLING AND WELL COMPLETION, SPILL SIZE - 300 m³

REGION	COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB. MTBF
Beaufort Sea Shallow	w	1.6E-4				1.6E-4 6200
	s	1.5E-4	-	NA	NA	1.5E-4 6700
Beaufort Sea Deep	w	1.6E-4				1.6E-4 6200
	s	1.5E-4	-	NA	NA	1.5E-4 6700
Arctic Islands		1.3E-4	-	NA	NA	1.3E-4 7700
Labrador Sea		1.5E-4	-	NA	NA	1.5E-4 6700

TABLE 3.12

PHASE-DEVELOPMENT DRILLING AND WELL COMPLETION, SPILL SIZE - 3000 m³

REGION	COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB. MTBF
Beaufort Sea Shallow	w	4.1E-5				4.1E-5 24,000
	s	3.8E-5	-	NA	NA	3.8E-5 26,000
Beaufort Sea Deep	w	4.1E-5				4.1E-5 24,000
	s	3.8E-5	-	NA	NA	3.8E-5 26,000
Arctic Islands		3.2E-5	-	NA	NA	3.2E-5 31,000
Labrador Sea		3.8E-5	-	NA	NA	3.8E-5 26,000

Comments:

BO = Blowout
 RS = Rig Spill
 OS = Other System
 PL = Pipeline
 NE = Not Estimated

NA = Not Applicable
 - = Zero or Negligible
 w = Winter
 s = Summer

Note:

Probabilities per well per year (or per season).

TABLE 3.13

PHASE-DEVELOPMENT DRILLING AND WELL COMPLETION, SPILL SIZE - 30,000 m³

REGION		COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea	w	2.0E-6				2.0E-6	500,000
	s	1.8E-6	-	NA	NA	1.8E-6	550,000
Beaufort Sea	w	2.0E-6				2.0E-6	500,000
	s	1.8E-6	-	NA	NA	1.8E-6	550,000
Arctic Islands		1.6E-6	-	NA	NA	1.6E-6	620,000
Labrador Sea		1.8E-6	-	NA	NA	1.8E-6	550,000

TABLE 3.14

PHASE-START-UP AND STEADY STATE PRODUCTION, SPILL SIZE - 3 m³

REGION		COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea		NE	1.8E-2	1.1E-1	NA	1.3E-1	7.4
	Shallow						
Beaufort Sea		NE	1.8E-2	1.0E-1	NA	1.2E-1	8.1
	Deep						
Arctic Islands		NE	4.9E-2	1.1E-1	2.3E-1	1.5E-1	6.0
Labrador Sea		NE	4.9E-2	1.2E-1	NA	1.6E-1	5.6

Comments:

BO = Blowout
 RS = Rig Spill
 OS = Other System
 PL = Pipeline
 NE = Not Estimated

NA = Not Applicable
 - = Zero or Negligible
 w = Winter
 s = Summer

Note:

Probabilities per well per year (or per season).

TABLE 3.19

PHASE-ABANDONMENT, SPILL SIZE - 3 m³

REGION	COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
	BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea Shallow	NE	1.7E-2	1.2E-1	NA	1.3E-1	6.9
Beaufort Sea Deep	NE	1.7E-2	1.0E-1	NA	1.2E-1	8.2
Arctic Islands	NE	4.9E-2	1.1E-1	NA	1.5E-1	6.0
Labrador Sea	NE	4.9E-2	1.3E-1	NA	1.7E-1	5.3

TABLE 3.20

PHASE-ABANDONMENT, SPILL SIZE - 30 m³

REGION	COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
	BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea Shallow	w	2.4E-3			1.7E-2	58
	s	2.1E-3	6.2E-4	1.4E-2	1.7E-2	59
Beaufort Sea Deep	w	2.4E-3			1.4E-2	71
	s	2.1E-3	6.2E-4	1.1E-2	1.4E-2	73
Arctic Islands		2.0E-3	2.0E-3	1.2E-2	1.6E-2	62
Labrador Sea		2.2E-3	2.0E-3	1.5E-2	1.9E-2	52

Comments:

BO = Blowout
 RS = Rig Spill
 OS = Other System
 PL = Pipeline
 NE = Not Estimated

NA = Not Applicable
 - = Zero or Negligible
 w = Winter
 s = Summer

Note:

Probabilities per well per year (or per season).

TABLE 3.21

PHASE-ABANDONMENT, SPILL SIZE - 300 m³

REGION		COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea Shallow	w	2.0E-4				5.7E-4	1800
	s	1.8E-4	-	3.7E-4	NA	5.5E-4	1800
Beaufort Sea Deep	w	2.0E-4				6.4E-4	1600
	s	1.8E-4	-	4.4E-4	NA	6.2E-4	1600
Arctic Islands		1.4E-4	-	7.3E-5	NA	2.1E-4	4700
Labrador Sea		1.6E-4	-	5.5E-4	NA	7.1E-4	1400

TABLE 3.22

PHASE-ABANDONMENT, SPILL SIZE - 3000 m³

REGION		COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea Shallow	w	4.9E-5				2.5E-4	4000
	s	4.5E-5	-	2.0E-4	NA	2.4E-4	4100
Beaufort Sea Deep	w	4.9E-5				2.9E-4	3500
	s	4.5E-5	-	2.4E-4	NA	2.8E-4	3500
Arctic Islands		3.6E-5	-	4.0E-5	NA	7.6E-5	13,000
Labrador Sea		4.0E-5	-	3.0E-4	NA	3.4E-4	2900

Comments:

BO = Blowout
 RS = Rig Spill
 OS = Other System
 PL = Pipeline
 NE = Not Estimated

NA = Not Applicable
 - = Zero or Negligible
 w = Winter
 s = Summer

Note:

Probabilities per well per year (or per season).

TABLE 3.15

PHASE-START-UP AND STEADY STATE PRODUCTION, SPILL SIZE - 30 m³

REGION		COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea	w	1.3E-3				1.6E-2	62
	s	1.2E-3	6.2E-4	1.4E-2	NA	1.6E-2	63
Beaufort Sea	w	1.3E-3				1.3E-2	77
	s	1.2E-3	6.2E-4	1.1E-2	NA	1.3E-2	78
Arctic Islands		9.9E-4	2.0E-3	1.2E-2	2.1E-1	2.2E-1	4
Labrador Sea		1.2E-3	2.0E-3	1.5E-2	NA	1.8E-2	55

TABLE 3.16

PHASE-START-UP AND STEADY STATE PRODUCTION, SPILL SIZE - 300 m³

REGION		COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea	w	1.1E-4				4.8E-4	2100
	s	9.9E-5	-	3.7E-4	NA	4.7E-4	2100
Beaufort Sea	w	1.1E-4				5.5E-4	1800
	s	9.9E-5	-	4.4E-4	NA	5.4E-4	1900
Arctic Islands		7.2E-5	-	7.3E-5	7.3E-2	7.3E-2	13
Labrador Sea		8.8E-5	-	5.5E-4	NA	6.4E-4	1600

Comments:

BO = Blowout
 RS = Rig Spill
 OS = Other System
 PL = Pipeline
 NE = Not Estimated

NA = Not Applicable
 - = Zero or Negligible
 w = Winter
 s = Summer

Note:

Probabilities per well per year (or per season).

TABLE 3.17

PHASE-START-UP AND STEADY STATE PRODUCTION, SPILL SIZE - 3000 m³

REGION		COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea Shallow	w	2.7E-5				2.3E-4	4400
	s	2.5E-5	-	2.0E-4	NA	2.2E-4	4400
Beaufort Sea Deep	w	2.7E-5				2.7E-4	3700
	s	2.5E-5	-	2.4E-4	NA	2.6E-4	3800
Arctic Islands		1.8E-5	-	4.0E-5	1.4E-2	1.4E-2	71
Labrador Sea		2.2E-5	-	3.0E-4	NA	3.2E-4	3100

TABLE 3.18

PHASE-START-UP AND STEADY STATE PRODUCTION, SPILL SIZE - 30,000 m³

REGION		COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea Shallow	w	1.3E-6				1.3E-6	770,000
	s	1.2E-6	-	-	NA	1.2E-6	830,000
Beaufort Sea Deep	w	1.3E-6				1.3E-6	770,000
	s	1.2E-6	-	-	NA	1.2E-6	830,000
Arctic Islands		8.8E-7	-	-	-	8.8E-7	1,100,000
Labrador Sea		1.1E-6	-	-	NA	1.1E-6	910,000

Comments:

BO = Blowout
 RS = Rig Spill
 OS = Other System
 PL = Pipeline
 NE = Not Estimated

NA = Not Applicable
 - = Zero or Negligible
 w = Winter
 s = Summer

Note:

Probabilities per well per year (or per season).

TABLE 3.23

PHASE-ABANDONMENT, SPILL SIZE - 30,000 m³

REGION		COMBINED DIVISION PROBABILITY				TOP EVENT PROBABILITY	
		BO	RS	OS	PL	PROB.	MTBF
Beaufort Sea Shallow	w	2.4E-6				2.4E-6	420,000
	s	2.2E-6	-	-	NA	2.2E-6	450,000
Beaufort Sea Deep	w	2.4E-6				2.4E-6	420,000
	s	2.2E-6	-	-	NA	2.2E-6	450,000
Arctic Islands		1.8E-6	-	-	NA	1.8E-6	560,000
Labrador Sea		2.0E-6	-	-	NA	2.0E-6	500,000

Comments:

BO = Blowout
 RS = Rig Spill
 OS = Other System
 PL = Pipeline
 NE = Not Estimated

NA = Not Applicable
 - = Zero or Negligible
 w = Winter
 s = Summer

Note:

Probabilities per well per year (or per season).

TABLE 3.24

OVERALL SPILL PROBABILITIES FOR DRILLING AND PRODUCTION SYSTEMS
PER YEAR

REGION	PHASE	SPILL SIZE m^3					EXPECTED NUMBER OF SPILLS	EXPECTED VOLUME OF SPILLS m^3
		3	30	300	3,000	30,000		
Beaufort Sea - Shallow (10 Wells)	DC	4.8E-3	1.9E-2	1.5E-3	3.9E-4	1.9E-5	2.6E-2	2.8
	SP	7.5E-1	1.5E-1	4.7E-3	2.2E-3	1.2E-5	1.6	19.0
	AB	7.5E-1	1.6E-1	5.6E-3	2.4E-3	2.3E-5	1.5	19.0
Beaufort Sea - Deep (20 Wells)	DC	9.6E-3	3.8E-2	3.1E-3	7.9E-4	3.8E-5	5.2E-2	5.6
	SP	9.2E-1	2.3E-1	1.1E-2	5.3E-3	2.4E-5	2.9	35.0
	AB	9.2E-1	2.5E-1	1.3E-2	5.7E-3	4.6E-5	2.8	38.0
Arctic Islands (10 Wells)	DC	4.0E-2	2.1E-2	1.3E-3	3.2E-4	1.6E-5	6.4E-2	2.6
	SP	8.4E-1	3.2E-1	8.1E-2	1.5E-2	8.8E-6	2.3	85.0
	AB	8.0E-1	1.5E-1	3.3E-3	1.4E-3	1.8E-5	1.8	15.0
Labrador Sea (10 Wells)	DC	4.0E-2	2.5E-2	1.5E-3	3.8E-4	1.8E-5	6.8E-2	3.0
	SP	8.3E-1	1.5E-1	6.4E-3	3.2E-3	1.1E-5	2.1	15.0
	AB	8.4E-1	1.7E-1	7.1E-3	3.4E-3	2.0E-5	2.1	24.0

DC = Development Drilling and Well Completion

SP = Start-Up and Steady State Production

AB = Abandonment

one ship in each of the four other regions. In the Labrador Sea/Davis Strait region, one of the ships is in coastal waters and two are assumed to be "at sea". Here "at sea" is defined as being more than 50 nautical miles (93 km) from any shore. The eighth ship is assumed to be in southern waters.

Further, the shipping year has been divided into two seasons; nominally summer and winter, in which either low (summer) or high (winter) ice pack densities are encountered.

3.3.1.2 Ship Hazards

For each of the ten region/season combinations, shipping systems reliabilities have been estimated for five hazards or groups of hazards. These are:

Grounding

Collision

Ramming

Structural Failure

Other

Here "Structural Failure" includes vibrations, wear and tear, heavy weather and foundering. "Other" includes fire, explosion, break-down and capsizing.

3.3.1.3 Data Sources

For the subsequent analyses of this section there are four principal sources of data. Three of these are summary analyses of worldwide data which relate spill sizes and spill incidence rates to accident occurrence rates. The fourth source is an analysis by Lloyd's Register of Shipping giving the basic accident incident rates (Lloyd's Register, proprietary information). Lloyd's Register has further made predictions of the expected accident rates for a large ship operating in the Labrador Sea. The estimates presented in this study are based on Lloyd's Register's estimates for future traffic densities in the area. The predicted rates are interpreted in terms of accidents per ship per year (or season) of operation.

3.3.1.4 Description of the Logic for the Ship Transportation System

For each of the hazards considered the spill risk is assessed following the method depicted in Figure 3.6, Risk Methodology. The hexagonal symbols  represent scaling operations (logical conditionals). The symbol  represents the logical 'OR' operation, and is in this case, essentially a summing mode.

The analyses reflect the relative importance of port versus coastal versus at sea shipping patterns. In addition, an attempt has been made to estimate the effects of double-hulling on PCI (Pollution Causing Incident) rates.

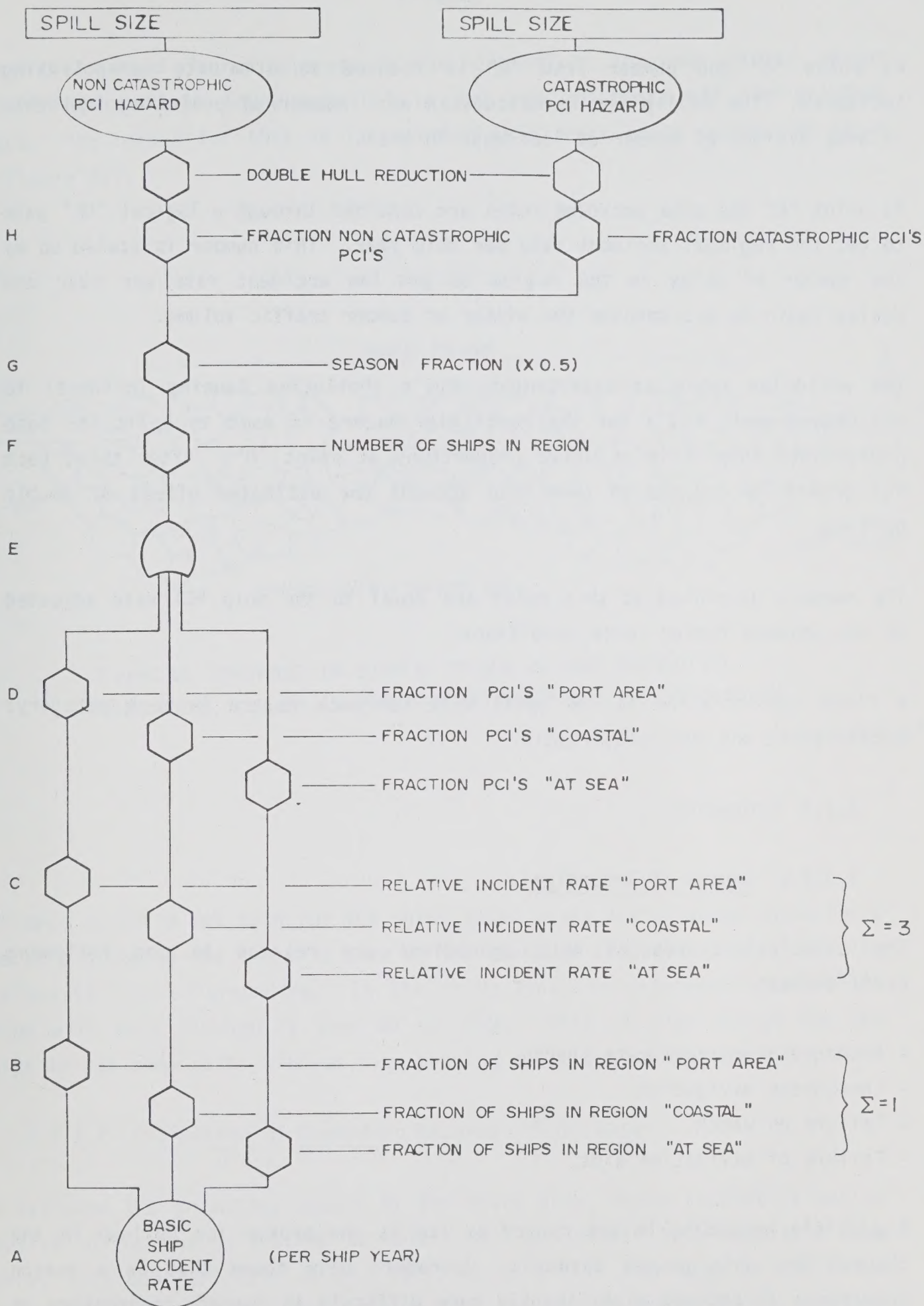
Figure 3.6 demonstrates the logical process used to calculate the risks associated with the transportation system. As mentioned in Section 3.2.2, the results generated by this process are not meant to be rigorous, extremely accurate reliabilities. These numbers are calculated simply to help indicate those areas or operations most prone to failure and in the greatest need of further study.

At point "A" of Figure 3.6 the basic ship accident rate is taken as the base number from worldwide statistics, for a certain type of hazard (collision, grounding, etc.). This number is modified to reflect traffic densities.

At point "B" the base number is split three ways to represent what fraction of the tankers under consideration will be in port, coastal, and at sea areas. The sum of these fractions must equal one. As an example, in the Labrador Sea Region, ships may be expected to be "at sea" 2/3 of the time, "in port" 1/6 of the time and "in coastal" areas 1/6 of the time. In Lancaster Sound the ships may be expected to be "in coastal" waters 100% of the time and never "in port" or "at sea".

At point "C" the relative incident rate in each area (port, coast and sea) is multiplied by the number from "B". The relative incident rate is equal to:

$$\frac{\text{number of incidents in a specified area}}{\text{number of incidents}} \times \text{number of areas}$$



At point "D" the number from "C" is reduced to eliminate non-polluting incidents. The multiplier is calculated as: number of polluting incidents in area divided by number of incidents in area.

At point "E" the area accident rates are combined through a logical "OR" gate to get the regional accident rate per ship year. This number is scaled up by the number of ships in the region to get the accident rate per year and scaled again to accommodate the winter or summer traffic volume.

The worldwide ratio of catastrophic PCI's (Pollution Causing Incident) to non-catastrophic PCI's for the particular hazard is used to split the base probability into their relative proportions at point "H". After this, each PCI branch is reduced to take into account the estimated effect of double hulling.

The numbers generated at this point are equal to the ship PCI rate adjusted to the assumed tanker route conditions.

A final consideration is the spill size for each hazard in each category: catastrophic and non-catastrophic.

3.3.2 Grounding

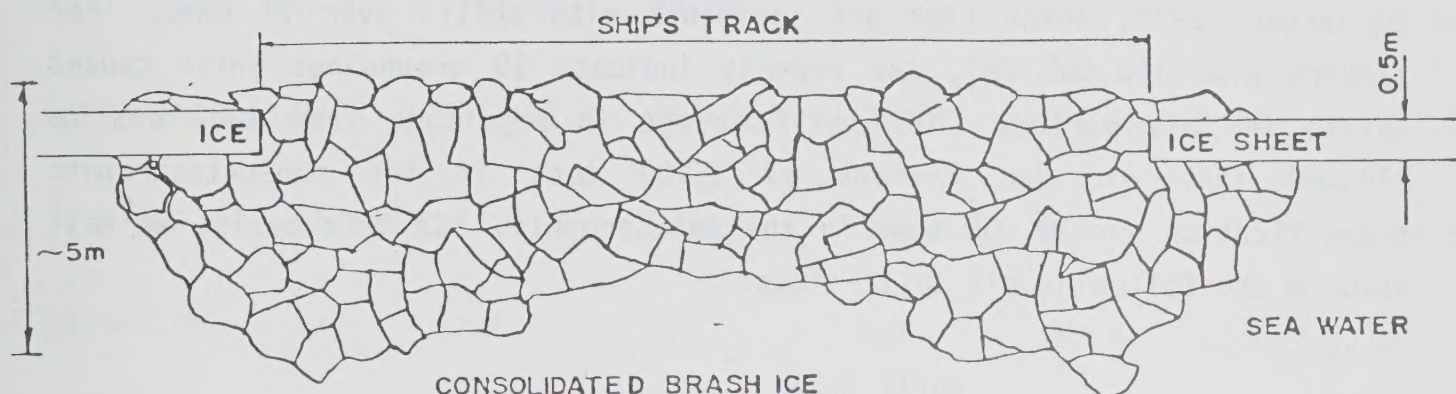
3.3.2.1 Causes of Grounding

The principal causes of ship groundings are related to the following deficiencies:

- Inadequate or inaccurate charts.
- Inaccurate navigation.
- Failure on watch.
- Failure of navigation aids.

A possible grounding hazard caused by ice is the broken ice buildup in the channel the ship passes through. Operators have found that as a season progresses it becomes significantly more difficult to operate icebreakers or

commercial ships in an already broken channel. In some cases, easier travelling could be found parallel to and some distance off the original track. The reason for this is illustrated by a track cross section as shown in Figure 3.7.



TYPICAL PROFILE IN SHIP'S TRACK AFTER REPEATED PASSAGES, LULEA HARBOUR, 1977 (AFTER BENGTTSSON, 1977)

FIG. 3.7

The need to cut a new path for the ships after every few passages could force the ship close to the shore in some of the narrower channels, thus increasing the possibility of grounding. In the study area, the narrowest channel the ships will pass through is some 20 km wide. This is wide enough for the ships to cut many paths without ever passing too close to the shore.

3.3.2.2 Estimation of Grounding Hazards - Data Base

To estimate the grounding hazard in the study area, world statistics can be applied to the design systems to obtain reliabilities. Data available from Henry, 1975 and Poricelli et al, 1973, cover a five year span in which 950 grounding incidents are cited. These data are summarized in Tables 3.25 and

3.26. The events are categorized into local (pier, harbour, entrance), coastal, sea and unknown. The data are further divided into pollution causing incidents (PCI's) and non-polluting incidents. Another reference, Canadian Coast Guard, 1977, further breaks the PCI's into catastrophic and non-catastrophic PCI's. These data are summarized in Table 3.27. For groundings, the average outflow from a non-catastrophic PCI is 919 tons and for a catastrophic PCI is 13,350 tons. Other statistical data were made available through Lloyd's Weekly Casualty Reports for the period January 1972 to January 1979, which list all incidents with spills over 70 tons. For tankers over 100,000 DWT, the reports indicate 10 groundings which caused spills in this period. The spills range in magnitude from 100 tons to 220,000 tons with an average of 1,100 tons in the non-catastrophic classification and 92,000 tons in the catastrophic. On this basis, we have assumed the following oil spill sizes:

	Spill Size Class m ³
Non-Catastrophic	1,000- 10,000
Catastrophic	10,000-100,000

3.3.2.3 Scaling of Data Base to Reflect Ships and Area Studied

Application of worldwide grounding statistics presumes that the proposed navigable waterways would be charted as thoroughly and accurately as the more common commercial waterways. At present this is not the case. Furthermore, the presence of ice provides constraints on navigable waterways. Thus the actual hazard may imply greater risk than worldwide statistics would indicate.

The data used here readily yield a non-catastrophic PCI rate per ship-year. This figure has been scaled to give the expected grounding incident rate and the catastrophic PCI rate. These rates have been further modified, first, to reflect the traffic density in a region, and second, to reflect the nature of that traffic. For example, in the Labrador Sea/Davis Strait region we have assumed that there are three petroleum production ships operating at any instant. However, two of these ships are assumed to be "at sea". Since the

TABLE 3.25

WORLDWIDE TANKER POLLUTION CAUSING INCIDENTS 1969 AND 1970

Poricelli et al

	<u>Piers</u>	<u>Harbours</u>	<u>Entrances</u>	<u>Coastal</u>	<u>Sea</u>	<u>Unknown</u>	<u>Total</u>
Collisions	6/19	18/136	25/80	29/76	2/12	1/15	81/338
Groundings	0/4	17/105	26/170	25/59	0/1	2/27	70/366
Rammings	15/138	6/50	2/18	1/10	0/2	0/4	24/222
Structural	4/5	2/2	3/3	1/4	38/184	3/13	51/216
Explosions	7/10	0/2	0/1	3/3	5/13	1/3	16/32
Fires	11/39	2/11	1/2	2/8	4/28	0/7	20/95
Break-downs	0/2	0/9	0/9	1/22	2/100	1/2	4/144
Other	-	-	-	-	-	3/3	3/3

A/B

A - Pollution causing incidents 1969 and 1970.

B - Total incidents 1969 and 1970.

Two-year summary of tanker accidents by cause, location and spill incidence. Each number pair gives for a cause/location, first the total number of spill incidents, and second the total number of incidents. This summary is based on worldwide statistics for all tanker sizes.

TABLE 3.26

WORLDWIDE TANKER POLLUTION CAUSING INCIDENTS 1971 AND 1972

Henry, 1973

	<u>Piers</u>	<u>Harbours</u>	<u>Entrances</u>	<u>Coastal</u>	<u>Sea</u>	<u>Unknown</u>	<u>Total</u>
Collisions	5/28	35/225	16/57	36/110	5/12	0/15	97/447
Groundings	0/3	31/139	23/77	46/119	0/0	1/5	101/343
Rammings	5/58	12/116	2/12	0/8	2/7	1/11	22/212
Structural	11/14	4/14	2/3	7/18	40/157	0/18	64/225
Explosions	12/20	5/10	0/1	6/15	8/22	0/2	31/70
Fires	21/43	4/13	0/1	6/13	2/20	1/4	34/94
Break-downs	1/4	2/21	1/7	4/67	7/79	0/6	15/182
Capsizing	2/2	2/2	0/0	4/5	4/4	0/1	12/14

A/B

A - Pollution causing incidents 1971 and 1972.

B - Total incidents 1971 and 1972.

Two-year summary of tanker accidents by cause, location and spill incidence. Each number pair gives for a cause/location, first the total number of spill incidents, and second the total number of incidents. This summary is based on worldwide statistics for tankers over 100 GRT.

TABLE 3.27

WORLDWIDE TANKER POLLUTION CAUSING INCIDENTS 1969-1974

Canada Coast Guard (Termpol) 1977

	TOTAL I	NON- CATASTROPHIC PCI's	OUTFLOW/ PCI	CATASTROPHIC PCI's	OUTFLOW/ PCI	TOTAL OUTFLOW
Collisions	895	141	416 T	10	17,306 T	232,000 T
Groundings	950	132	919 T	14	13,350 T	308,000 T
Rammings	550	51	284 T	0	0	14,000 T
Structural	587	87	209 T	15	21,501 T	341,000 T
Break-downs	409	9	66 T	3	16,058 T	49,000 T
Explosions	127	25	293 T	15	8,486 T	135,000 T
Fires	240	16	105 T	1	1,250 T	3,000 T
Miscellaneous	<u>5</u>	<u>1</u>	121 T	<u>3</u>	18,263 T	<u>55,000 T</u>
Total	3,763	462		61		1,137,000 T

Five-year summary of pollution causing incidents, by cause, spill size, and incidence. The first column shows the total number of shipping accidents by cause, including non-polluting incidents. The second and fourth columns show the number of pollution causing incidents in two categories. The third and fifth columns give the respective mean outflow quantities. The sixth column gives the total outflow for major and minor PCI's.

This summary is based on worldwide statistics for tankers larger than 3,000 DWT.

TABLE 3.27 (CONT'D.)

WORLDWIDE TANKER POLLUTION CAUSING INCIDENTS 1969-1974

Worldwide tanker pollution causing incidents for tankers greater than 3,000 DWT (excluding catastrophic accidents). Number and type of accident per port of call.

<u>Cause</u>	<u>No. of Ports of Call/PCI</u>
<u>Worldwide</u>	
Collision	6,651
Grounding	7,105
Ramming	18,389
Structural Failure	10,780
Explosion	18,035
Fire	12,030
Miscellaneous	6,005

Valdez

Collision and Ramming (Two Transits/Port of Call)	5,479
--	-------

data indicate that no PCI's resulting from grounding occur "at sea", the PCI estimates are modified accordingly.

The final modification of the rates involves compensating for the extra strength expected in the design ships. Card (1975) provides convincing evidence that up to 90% of PCI's resulting from grounding would be avoided if vessels had double bottoms adequately separated. We have assumed that the design ships will be double-hulled icebreakers and that non-catastrophic PCI's from grounding will be significantly reduced. The reduction factor we have chosen is 0.2.

Double hulling has been reviewed with regard to the risk of a catastrophic PCI from grounding. In this case the tanker is required to be irrecoverably stranded, eventually breaking-up, leading to a catastrophic spill. Double hulls provide features which would tend to prevent such an incident from becoming a catastrophe:

- . Increased strength from the double hull.
- . Containment of the cargo by entrapment in the double hull.
- . Slower discharge, allowing additional response time for salvage and lightering.

These aspects are the subject of extensive specialist discussion (Card, 1975). Catastrophic spills from grounding were not found to be an overall common occurrence, and for the purposes of this study, spillage risks obtained from statistical data have been used without further modification.

3.3.3 Collision

3.3.3.1 Causes of Collision

Ship collision is defined as ship to ship contact when both ships are under way. Although loss of ship control due to mechanical failure can cause

collisions, the principal cause of collisions is human error. Under severe ice conditions, collisions resulting from mechanical failures may become more common. However, specialized Arctic equipment should help to nullify this risk. The most significant parameter affecting collision rates is traffic density, with the collision rate being roughly proportional to ship to ship encounter rates.

3.3.3.2 Data Base and Assumptions Related to Collision

Expected collision rates have been estimated as follows. The basic datum is a collision rate estimate for the Labrador Sea, based on current traffic densities on the Eastern Canadian Seaboard. By making assumptions about traffic densities in the other regions, collision rates can then be scaled. These assumptions are that:

- Traffic densities in the Labrador Sea/Davis Strait are constant year round.
- Traffic density in Parry Channel/Lancaster Sound (summer only) is the same as for the Labrador Sea/Davis Strait.
- Traffic density in the Beaufort Sea (summer only) is half of that in Labrador Sea/Davis Strait.
- Traffic in Beaufort Sea/Parry Channel/Lancaster Sound in winter is small in comparison to other regions or seasons.

Expected spillage rates are then scaled from worldwide collision incident rates. The Canadian Coast Guard (1977) states that for a five year period, of a total of 894 collision incidents there were 141 non-catastrophic spills with an average outflow of 416 tons, and 10 catastrophic spills with an average outflow of 17,306 tons. Statistical data available through Lloyd's Weekly Casualty Reports indicate a non-catastrophic PCI spill in the range of 1,000 to 10,000 m³, and a catastrophic spill in the range of 10,000 to 100,000 m³.

A final adjustment is required to compensate for the additional reliability resulting from the double hulling of the design ship. As with grounding, we have assumed that the non-catastrophic spill rate can be reduced by a factor of 0.2.

3.3.4 Ramming

Ramming, or the striking of a fixed object (not a ship), is a common damage causing incident. Data from the Canadian Coast Guard (1977) indicate that one in ten ramming incidents cause non-catastrophic spills averaging 284 tons outflow. Since it is a reliable statistic close to the study areas, we have assumed that the damage rate estimated for Valdez Inlet, of $9.12\text{E-}5$ accidents per transit is valid for the Arctic. World statistics based on the world tanker fleet indicate a poorer average reliability than Valdez. The port of Valdez utilizes more modern vessels than the world average.

Double-hulling would probably further reduce the likelihood of a ramming PCI.

For the purposes of this study, it is concluded that the PCI rate for ramming would be a small fraction of the total PCI rate and can be neglected.

3.3.5 Structural Failure

Structural failure includes any form of damage which results from fatigue. The large majority (84%) of structural failures occur "at sea", probably associated with excessive stress caused by heavy weather on the open water.

Data from the Canadian Coast Guard (1977) indicate that structural failure is the single most significant source of accidental oil pollution from shipping. Catastrophic failures were the cause of 95% of structural failure out-flow and 28% of all accidental out-flow. Since collision out-flow in the Arctic should be less than world averages due to the lower traffic levels, structural failure will become proportionally more significant. In this study, no estimate has been made regarding the effect of double hulled or ice

strengthened vessels on ship reliability due to structural failure. This is clearly a point for future consideration.

The rates presented in Tables 3.28 to 3.37 reflect world statistics. They are modified only to reflect local traffic conditions.

3.3.6 Other Categories

The grouping of casualty causes includes all the causes which may be considered to occur independently of region, area type or time. They include:

- Explosions
- Fires
- Break-downs
- Capsizings
- Miscellaneous

Combined they produce more catastrophic PCI's than either collisions, groundings or structural failures.

The failure rates presented in Tables 3.28 to 3.37 reflect world data modified to accommodate differing traffic levels. The data have not been adjusted for special design features, such as multiple and stand-by systems or inert gas systems, and are thus conservative.

3.3.7 Damage by Ice

The worldwide statistics of ship damage show damage by ice as a negligible cause of risk. Ships generally avoid iceberg infested waters.

A detailed study carried out by FENCO, Lloyd's Register and German + Milne showed that collision with potentially damaging ice is largely due to human error. Other studies have shown (Bureau Veritas, 1975) that no detection gear or any combination of radar, sonar, infrared T.V. or visual surveillance is reliably capable of detecting icebergs and multi-year ice. Thus, normal

ship operating procedures in Canadian Arctic waters must be supplemented with procedures to deal with hazards due to ice.

It is assumed that procedures such as helicopter surveillance, combined with improved detection equipment will reduce the probability of ice damage to very low levels, and such probabilities are not included in this analysis. However, this is an important area for future consideration.

3.3.8 Tables Summarizing Probabilities

Tables 3.28 to 3.37 summarize by region, season and cause the likelihood of an accident and of a spill of a specific size. The values are estimates of the probability of a given incident occurring at least once during a given year. Since seasonality and regionality are exclusive, the total incident rates are simple summations.

TABLE 3.28

Labrador/Davis Strait - Summer

	Total Events	300 m ³ PCI's	3,000 m ³ PCI's	30,000 m ³ PCI's
Collision	4.64E-2	-	1.46E-3	5.18E-4
Grounding	2.87E-2	-	1.59E-3	4.23E-4
Structural Failure	4.60E-2	7.40E-3	-	1.29E-3
Other	4.43E-2	3.43E-3	-	1.37E-3
Total	1.16E-1	1.08E-2	3.05E-3	3.60E-3

TABLE 3.29

Labrador/Davis Strait - Winter

Collision	2.33E-2	-	7.36E-4	2.61E-4
Grounding	2.87E-2	-	1.59E-3	4.23E-4
Structural Failure	4.60E-2	7.40E-3	-	1.29E-3
Other	4.43E-2	3.43E-3	-	1.37E-3
Total	1.42E-1	1.08E-2	2.33E-3	3.34E-3

TABLE 3.30

Parry Channel - Summer, at Ports

	Total Events	300 m ³ PCI's	3,000 m ³ PCI's	30,000 m ³ PCI's
Collision	3.09E-2	-	4.87E-4	1.73E-4
Grounding	1.91E-2	-	1.06E-3	2.82E-4
Structural Failure	0.53E-2	2.37E-3	-	4.07E-4
Other	2.95E-2	2.29E-3	-	9.15E-4
Total	8.48E-2	4.66E-3	1.55E-3	1.95E-3

TABLE 3.31

Parry Channel - Winter, Ports

Collision	-	-	-	-
Grounding	1.91E-2	-	1.06E-3	2.82E-4
Structural Failure	0.53E-2	2.37E-3	-	4.07E-4
Other	2.95E-2	2.29E-3	-	9.15E-4
Total	5.39E-2	4.66E-3	1.06E-3	1.60E-3

TABLE 3.32

Lancaster Sound - Summer, Coastal

	Total Events	300 m ³ PCI's	3,000 m ³ PCI's	30,000 m ³ PCI's
Collision	1.55E-2	-	4.87E-4	1.73E-4
Grounding	1.91E-2	-	1.06E-3	2.82E-4
Structural Failure	0.22E-2	0.74E-3	-	1.27E-4
Other	2.95E-2	2.29E-3	-	9.15E-4
Total	6.63E-2	3.03E-3	1.55E-3	1.50E-3

TABLE 3.33

Lancaster Sound - Winter, Coastal

Collision	-	-	-	-
Grounding	1.91E-2	-	1.06E-3	2.82E-4
Structural Failure	0.22E-2	0.74E-3	-	1.27E-4
Other	2.95E-2	2.29E-3	-	9.15E-4
Total	5.08E-2	3.30E-3	1.06E-3	1.32E-3

TABLE 3.34

Beaufort Sea - Summer, Ports

	<u>Total Events</u>	<u>300 m³ PCI's</u>	<u>3,000 m³ PCI's</u>	<u>30,000 m³ PCI's</u>
Collision	1.09E-2	-	3.42E-4	1.21E-4
Grounding	2.68E-2	-	1.48E-3	3.94E-4
Structural Failure	0.53E-2	2.37E-3	-	4.07E-4
Other	2.95E-2	2.29E-3	-	9.15E-4
Total	7.25E-2	4.66E-3	1.82E-3	1.84E-3

TABLE 3.35

Beaufort Sea - Winter, Ports

Collision	-	-	-	-
Grounding	2.68E-2	-	1.48E-3	3.94E-4
Structural Failure	0.53E-2	2.37E-3	-	4.07E-4
Other	2.95E-2	2.29E-3	-	9.15E-4
Total	6.16E-2	4.66E-3	1.48E-3	1.72E-3

TABLE 3.36

Beaufort Sea - Summer, Coastal

	<u>Total Events</u>	<u>300 m³ PCI's</u>	<u>3,000 m³ PCI's</u>	<u>30,000 m³ PCI's</u>
Collision	0.47E-2	-	1.46E-4	0.52E-4
Grounding	1.15E-2	-	0.64E-3	1.69E-4
Structural Failure	0.22E-2	0.74E-3	-	1.27E-4
Other	2.95E-2	2.29E-3	-	9.15E-4
Total	4.79E-2	3.03E-3	0.94E-3	1.26E-3

TABLE 3.37

Beaufort Sea - Winter, Coastal

Collision	-	-	-	-
Grounding	1.15E-2	-	0.64E-3	1.69E-4
Structural Failure	0.22E-2	0.74E-3	-	1.27E-4
Other	2.95E-2	2.29E-3	-	9.15E-4
Total	4.32E-2	3.03E-3	0.64E-3	1.21E-3

4. ENVIRONMENTAL CONSEQUENCES OF HYDROCARBON SPILLS

4.1 Introduction

At a preliminary level, the study has considered the risk to the Arctic environment of possible oil spills from the production and transportation of hydrocarbons. The likely transportation routes and production sites have been identified and environmental data bases have been analysed to identify the principle environmental impacts of oil spills. Data gaps have been identified which may limit the ability to make confident predictions of impacts. The following nine hypothetical spill sites were selected for the development of impact assessments from specific data bases:

1. Mackenzie Bay
2. Beaufort Sea
3. Armstrong Point
4. Viscount Melville Sound
5. Sverdrup Basin
6. Allison Inlet
7. Cape Liddon
8. Cape Hay
9. Cape Harrison

These sites are shown on Figure 1.2 in Chapter 1. Predictions of spilled oil trajectories, potential slick sizes and portions of the water column affected by spilled oil were made for each site. The detailed environmental data and oil slick trajectory analyses are presented in Appendices A and B.

4.2 Biological Resources

Potential impacts were considered at each site for the major resource groups and their utilization through hunting and fishing:

- fish
- birds
- marine mammals

- plankton/invertebrates.

Data collection efforts included a review of marine environmental surveys and previous impact statements within the study areas. Resources were catalogued on the basis of two seasons: open-water and ice-covered.

4.3 Slick Modelling

Modelling of oil slick movement utilized first order analyses of maximum surface extent and the associated water column concentrations, based on conservative assumptions, to give worst case design spills. The analyses were performed using formulae and data available from the literature. The trajectories were based on mean wind and current conditions determined from available data. The sizes of the slicks were superimposed over the preselected spill sites to evaluate the probable level of effects from 30,000 m³ oil spills on each biological resource for each season.

4.4 Environmental Impacts

The designation of impact levels was based on a five-category classification system:

- major,
- moderate,
- minor,
- negligible impact
- insufficient information.

A major impact affects a whole population or species and causes a decline in abundance and/or change in distribution beyond which natural recruitment will not return the population or species, or any population or species dependant upon it, to its former level within several generations. A major impact could also be one that is detrimental to human resource utilization (e.g., subsistence hunting).

A moderate impact affects a portion of a population which may result in a change in abundance and/or distribution over one or more generations of that portion of the population or any population dependent on it. A moderate impact does not change the integrity of any population as a whole.

A minor impact affects a specific local sub-population over a short period of time (one generation or less) but has no effect on the total population and no other trophic impact.

A negligible impact has no significant or measurable effect.

The insufficient information category indicates that the available data base is inadequate to allow a reasonable assessment of the impact level or it implies a tentative designation resulting from limited data on the resource or behaviour of oil.

The detailed impact analyses are contained in Appendices A and B. The main results are recorded in the following sections.

4.5 Sites

Site 1 Mackenzie Bay (69°25'N, 136°W)

This nearshore site is located in shallow water less than ten metres deep near the mouth of the Mackenzie River. Data were analysed for this area as representing a production site. Tides are generally less than one metre. The nearshore area is covered with landfast ice during the winter. The open-water season lasts one to four months.

In the event of a large oil spill, major impacts are predicted for seabirds during both seasons as this is one of the most productive and important areas in the Arctic for this group. Millions of loons, swans, geese, ducks and shorebirds nest in or migrate throughout the area. The shallow water and coastline are particularly important as feeding habitat for many species at critical periods of their life cycle (e.g., migration, moulting).

A tentative designation of moderate impact has been established for marine mammals. This designation applies to beluga and bowhead whales during the open-water period. It also applies to polar bears, ringed and bearded seals during the season of ice-cover.

Other resources receiving a moderate impact rating included plankton/invertebrates and fish during both seasons.

Important gaps in the biological data base concern the degree of use of the offshore waters by seabirds, identification of feeding areas for whales and the summer range and migration routes of bowhead whales. To more accurately predict impacts on coastal feeding and nesting areas of birds, it would be essential to establish the frequency of storms which overwash these areas.

Site 2 Beaufort Sea (70°12'N, 135°W)

This site was chosen to represent an offshore production site. Although further offshore than Site 1, this area is characterized by relatively shallow water, less than fifty metres deep. This site may be covered at any time by offshore ice. Impacts for this site would be similar to those identified for Site 1.

In the event of a large oil spill, a major impact is identified for bowhead whales at this site which is on the route of their fall offshore migration. A tentative designation of moderate impact in the open-water season has been established for beluga whales, all species of seabirds and most fish species. The same designation has been identified for marine mammals including polar bears, ringed and bearded seals during the period of ice cover. Resources being moderately impacted during the open-water season include zoobenthos, seals, seabirds and several species of fish. Hunting and fishing would be moderately impacted.

There is a general lack of knowledge on food chain relationships in the southern Beaufort Sea - Mackenzie Bay area which makes the prediction of trophically linked impacts difficult.

Site 3 Armstrong Point (73°N, 122°30'W)

The Armstrong Point site is located on a likely transportation route through Prince of Wales Strait. This is the narrowest passage (20 km) between land masses of the entire route. The hypothetical spill site is located mid-way along the 200 km length of the strait. Water depths vary from 73 to 165 m and open water exists at this site from July to September.

In the event of a large oil spill in the spring or fall, a major impact would result for King Eider and Oldsquaw. Their migration routes take them through this area. A moderate impact for arctic char during the ice-free period is predicted due to their tendency to utilize the upper layers of the water column. Complete information is not available to forecast impacts during either season for plankton, benthic invertebrates, marine mammals or birds nesting in riparian habitat.

Information on physical conditions such as wind and current speeds and directions are not available to allow realistic modelling for this area. Biological data are also lacking for most resource groups.

Site 4 Viscount Melville Sound (74°40'N, 105°W)

The site selected in Viscount Melville Sound may be exposed to through tanker traffic travelling through the area and to local traffic calling at land based stations such as Bridport Inlet. This area is characterized by persistent ice-cover which decreases to 1/10 - 3/10 coverage in September. Water depths reach 549 m in this large body of water.

The biological data base for the area are very limited, but the information available suggests that this is an area of low biological activity. In the event of a large oil spill, the most severe impact predicted is a moderate one for polar bear during the open water season. Minor impacts, qualified by the lack of complete data, include the plankton/invertebrate and seabird components of the resource groups.

It is anticipated that movement of an oil spill in wintertime could be restricted. The ice melts throughout the spring and summer months and oil from a winter spill would impact the Barrow Strait and M'Clintock Channel areas after natural weathering had reduced toxicity to marine life.

Site 5 Sverdrup Basin (77°W)

This site is located in an area where water depths range from 100 - 500 m. Tidal amplitude is less than 1 m and the coastline is dominated by abundant sand and gravel deposits. This is the most northerly site selected for analysis. The area is characterized by persistent ice-cover with a minimum average of 4/10 - 6/10 occurring during September. The scant data available indicate currents are weak. The movement of spilled oil would be a slow process, resulting in continuing contamination over many years.

In the event of a large oil spill, a major impact is predicted for Ivory Gulls. The colony on Seymour Island is one of only two confirmed breeding areas in the Canadian Arctic. A moderate impact is predicted for polar bear and walrus year round due to their presence in the area, particularly in Penny Strait.

Very little is known of other biological resources in the area and this, combined with the lack of information on physical conditions severely limits the accuracy of impact predictions.

Site 6 Allison Inlet (75°N, 99°38'W)

Allison Inlet is located on the south coast of Bathurst Island. This site was selected because it could be a terminal for the transportation of petroleum products and would then be exposed to a high level of tanker traffic. Water depths in the area vary from 100 - 200 m. The area is characterized by highly variable periods of ice break-up and open water.

In the event of a large spill, a major impact is predicted for resource utilization in hunting and fishing. The area is used by the residents of Resolute who harvest marine mammals, waterfowl and char. Moderate impacts

are predicted for those birds which utilize the ice edges during migration and nest along the coast. Similar impact levels are predicted for polar bear, ringed seal and walrus. Detailed information is lacking for all resource groups, notably fishery resources and plankton/invertebrates. Predictions are further inhibited by the very limited information available on the physical environment.

Site 7 Cape Liddon (74°37'N, 91°13'W)

This site is in the Barrow Strait where water depths range from 165 - 238 m. The westward retreating spring ice edge passes through the area. The ice edge is the focal point of biological activity. Specific impact prediction is hampered due to variable timing of this retreat.

In the event of a large spill, major impacts are predicted for murre and Northern Fulmars which utilize the open water for feeding and migration. They use the adjacent coastal sites as breeding colonies. In this area, known colonies of these birds support a significant proportion of their world total breeding population. Moderate impacts are predicted for the fishery resource where little is known about stock sizes and seasonal movements. One major research need is for documentation of the timing of ice movement through this region.

Site 8 Cape Hay (74°6'N, 80°22'W)

Lancaster Sound is one of the most intensively studied areas of the Canadian Arctic. The Sound is about 260 km long and 60 km wide with depths varying from 200 - 700 m. Open water is present from June to October. A large oil spill could be carried throughout the Sound by currents and would impact the shorelines of Devon and Bylot Island as it was swept on to Baffin Bay.

In the event of a large spill, a major impact is predicted for the bowhead whale. Their population numbers are already low in the Eastern Arctic. Thick-billed Murres, Northern Fulmars, Black-legged Kittiwakes and Dovekies are also identified in the major impact designation during the period of open

water. A large proportion of the total populations of these species uses Lancaster Sound for nesting and feeding. Moderate impacts are predicted for representatives of all other resources groups including all species of fish, narwhal and beluga whales and polar cod. Open water hunting would suffer a moderate impact.

Extensive biological information is available for this area. However, questions still remain, particularly regarding the sensitivity to oiling of several species, including seals and narwhal.

Site 9 Cape Harrison (55°29'N, 57°30'W)

This site located off Hopedale, Labrador, is in water about 200 m deep and adjacent to the shelf edge. This area is one of oil exploration as well as being on the potential route for shipment of Arctic hydrocarbons to southern markets. The Labrador current flows south along this rocky coast. The tidal amplitude is less than three metres. The open water period is relatively long (July-December).

The impacts of a large oil spill would be major for harp and hooded seals which whelp on the ice during March and April. A major impact is predicted for Atlantic Puffins which nest on the coastal islands in significant numbers. Moderate impacts are noted for all offshore and inshore species of birds using open water. A moderate impact is also predicted for fishery resources during the open water period. Information is not available to allow a more definitive determination of the impact of an oil spill on all species of marine mammals, fish, and birds utilizing the inshore area.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Previous chapters of this report have outlined arctic petroleum production and transportation systems, identified the probability of spills and reviewed their environmental consequences. The analyses have been based on existing statistical data applied to hypothetical schemes and production levels which may be achieved through major projects in the future. The report has also discussed the uncertainties and inadequacies in basic data which could affect the relevance of the analyses. In this chapter, the report presents a summary of recommendations for overcoming these inadequacies and further recommendations for improvements in safety and reliability. This is followed by a brief summary of conclusions drawn from the study.

The recommendations are grouped under three general headings: information for production and transportation planning; environmental data; safety and reliability requirements.

5.2 Information for Production and Transportation Planning

In the development of facilities for arctic petroleum production and transportation, it is anticipated that every effort will be made to provide safe, reliable and effective systems. Planning and detailed engineering will make use of current knowledge, materials and techniques with appropriate provisions for uncertainties. However, production and transportation projects in this area will be very expensive undertakings, and particular consideration will be given to reducing the uncertainties. As new knowledge is developed in such aspects as ice forces, new materials or new techniques, engineering will apply the data to improve the systems and the economic advantages of the projects.

In preparation of the report, the following uncertainties and inadequacies in basic data have been identified.

a. Sea Ice Dynamics

For the purposes of offshore development activities in drilling, production and shipping, it is important to be able to predict with some accuracy such aspects as ice thickness, percentage ice cover and ice type. This would be accomplished through the development of regional sea ice models which would also provide useful information for sea ice break-up and freeze-up forecasting. To provide input for these models, systematic tracking of sea ice movement should be performed by satellite.

b. Ice Scour

Ice scour presents a considerable danger to subsea wellheads, equipment and pipelines. Research has been carried out to predict ice forces and scour depths. Further investigation is required to improve the accuracy of frequency estimates and to develop ice scour protection systems.

c. Icebergs

At present, information on iceberg movement is based on observations within the zone of the sea ice airborne reconnaissance program. There is no systematic iceberg dynamics program to allow accurate statistical analysis. Icebergs cannot be detected properly by satellite. Regional airborne iceberg detection is required.

d. Sea Bed Conditions

Bathymetric surveys and geologic surveys off the coasts of Canada are carried out by the Canadian Hydrographic Service of the Department of Fisheries and Oceans and by the Geological Survey of Canada of the Department of Energy, Mines and Resources. Modern maps are available for the Beaufort Sea and the Labrador Sea. However, much of the Arctic Archipelago remains unsurveyed from either a hydrographic or geologic standpoint.

If grounding incidents are to be avoided, bathymetric data must be made available. Sea bed conditions must be known to determine the feasibility and

performance of offshore structures and facilities. Slumping of the sea bed is a particular concern along the steep unstable sides of sounds and channels in the Arctic Islands. Slope induced slumps could bury or tear out wellhead equipment and control lines.

e. Oceanography

Surface currents and wave data are poorly documented for the Canadian offshore. Programs are underway for the east coast but these should be extended to include other areas. The programs should also include the effects of storms on currents at depth and the internal waves which result from the interaction of water layers of different densities.

f. Structural Performance

Materials used in arctic and offshore structures and vessels for components such as propellers, rudders and frames will be subjected to repeated impacts from ice. Research into the behaviour and materials in these conditions is essential to establish the feasibility of proposed systems.

The integrity of mooring systems for floating drilling or production platforms must be ensured to prevent large spills. Research is still required to enable more reliable prediction of anchor performance in conditions of very soft and loose sea bottom conditions in the Arctic Islands, strong currents and deep water off the east coast, rapid disengagement and recovery in ice infested waters and extra strong capability to withstand moderate ice.

g. Shipping

The analysis presented in the report has assumed that with advancing technology, regulation and training, the risks in arctic tanker transportation will not be significantly higher than in southern areas. The following considerations should be included in the design of the arctic petroleum tankers:

- . the ships should be double-hulled, with inert gas systems.

- . The ships should have secondary back-up systems for steering and propulsion.

5.3 Environmental Data

The recommendations in this section are concerned with improving the evaluation of marine environmental impacts from potential oil spills in the arctic. The species that are the focus of the biological portion of this study interact with each other in the natural environment and biological communities. The different communities interact with the chemical and physical characteristics of arctic waters to form ecosystems. There is insufficient broad scale information to permit comparative analyses of biological production and energy transfer processes. Future research requirements would include the following:

- . The relative roles of phytoplankton and epontic microflora in primary production processes, particularly in areas with extended ice cover.
- . The distributions, production dynamics and relative importance of macroalgae.
- . Distributions, densities, production potentials and sensitivity to oiling of nearshore terrestrial and brackish/freshwater pond vegetation (primarily for areas above the level of normal wave activity, but susceptible to storm surges).
- . The composition and distributions of benthic communities to allow identification of unique or important assemblages or species.
- . Growth rate data for marine benthic invertebrates.
- . Surficial sediment distributions and the benthic invertebrates associated with these sediments.
- . The composition, susceptibility to oiling damage and the ecological role of deeper water benthic communities.

Sensitive species have been identified on the basis of existing knowledge. Further in-depth study would assist in providing recommendations for minimizing impacts, such as direction for the use of dispersants.

In the course of the study, the following areas have been identified for future investigation.

a. Fish

Existing data on fish in arctic waters are generally catalogues of species occurrences. However, information on stock discreteness, replacement potential and abundance are also required. In most cases, the egg and larval stage are the most susceptible to oiling. On this basis, a study of spawning times and the distribution of early stages is required. The effects of oil on the ability of Arctic char to identify home streams should be evaluated. Additional concerns involve indirect effects of oil spills such as food chain disruption.

b. Marine Birds

The groups of marine birds which are particularly sensitive to oil spills include diving ducks, alcids and fulmars. Information on their stock discreteness, relative abundance and seasonal distribution, are required. Their reproductive success, as affected by ecological and environmental factors, is poorly understood. Data are also required on food chain interactions, daily energy requirements and background tissue hydrocarbon and pesticide levels to more readily assess potential indirect effects.

c. Marine Mammals

As with marine birds, the questions on stock discreteness and abundance arise. However, for most sites, seasonal distribution is understood or can be predicted. A major weakness in available information is the effect of oil. Food chain and potential indirect effects must also be identified.

d. Hunting and Fishing

Alternative hunting and fishing areas could be identified to minimize the impact on the hunting practices of the native people if their local populations of fish, birds or marine mammals were damaged. At present a number of the sites studied are not utilized by native peoples and potential utilization should be considered. It should also be noted that areas outside traditional hunting regions may serve as reservoirs for heavily exploited areas.

A continuing review of local resource harvesting practices would help to assess the disruptive potential of oil spills on local people, and to assign economic value to the resources.

5.4 Safety and Reliability Requirements

For the production and transportation of arctic petroleum, high levels of operational reliability will be essential to reduce economic losses which may be caused by accidents and failures. Experience gained in the Canadian Arctic and offshore areas in the exploration phase has emphasized the importance of safety and maintenance considerations. The extreme climate, the limited working spaces and safety precautions all restrict maintenance activity.

The following group of recommendations are related specifically to the improvement of safety and reliability.

a. Guidelines

Guidelines and standards should be established to cover the following aspects:

- . Design, construction and inspection, structural and environmental load requirements, materials and installation.

- . Safety assurance standards to minimize unsafe operating conditions and the chances for inadvertent damage or destruction of equipment or danger for personnel.
- . Quality assurance and an overall control system of enforcement throughout the phases of design, construction, operation and abandonment.

b. Monitoring

For offshore structures, remote monitoring techniques would offer an alternative to visual inspection by diver or submarine. Various techniques are available and require investigation for applications in steel and concrete structures in the arctic and offshore environments.

5.5 Conclusions

The study has shown that with adequate provision for the hazards, there are no insurmountable obstacles to the production and transportation of petroleum from the arctic. From the analysis, the main hazards in production and transportation can be summarized as follows:

a. Beaufort Sea - Shallow

In this area, the main hazard for production is ice. Earth islands have been used for exploration and designs have overcome the ice problems and provide safety against these forces. Experience indicates that safety can be improved so that risks will be comparable to activity in southern regions.

b. Beaufort Sea - Deep

Production in this area will be based on caisson retained atolls or islands. The main problems will be caused by arctic pack ice and summer storms. Design must consider these hazards using resilient steels and providing slope protection. With suitable defense, it is considered that risks will be reduced to levels comparable with southern waters.

c. Arctic Islands

In the Arctic Archipelago, hazards will be created by the ice and will require subsea production systems. The subsea systems would be affected by ice scour in shallow waters and by slope instability of the sea bed. Safety measures must be devised to bring the risks into acceptable levels.

d. Labrador Sea

Icebergs are the main hazard in the Labrador Sea. Collisions with icebergs represent the largest single hazard to production in these offshore waters. This includes the possibility of direct hits as well as the risks of blowout from well abandonment. It seems possible, within economic limits, that these risks can be brought to acceptable levels.

e. Transportation

The study has been based on petroleum transportation being provided by a fleet of 200,000 ton tankers, ice reinforced, class 10, with double hulls, resilient steels and improved detection devices. The study has concluded that the risks in tanker transportation will not be significantly higher than in southern areas. Indeed, from comparisons with the Valdez traffic, it is noted that with appropriate regulation, using tankers designed specifically for this route, the risks will be lower than those indicated in worldwide statistics.

6. REFERENCES

6.1 References, Chapter 2

Dome Petroleum Limited, Esso Resources Canada Ltd., and Gulf Canada Resources Inc., Beaufort/Mackenzie Delta Development Plan, Paper presented at conference, Calgary, Alberta, 120 pp, November 13, 1980.

King, C. M., and Mckenzie, D., Drilling Wells on Target, Offshore, p. 125, May 1980.

Le Blanc, L., Producing in Iceberg Lanes, Offshore, p. 56, October 1980.

Reimert, L. E., Design Principles for Multi-Well Subsea Production Equipment, Offshore Technology Conference, papers presented at 12th annual OTC in Houston, Texas, p. 449, May 5-8, 1980.

Offshore, Canada Pushing for 1985 Production, p. 149, May 1980.

Offshore, Air Cushion Rigs, A Challenge, p. 178, May 1980.

Offshore, Other Platforms Show Possibilities, p. 173, May 1980.

Offshore, Artificial Islands Safe Year-Round, p. 182, May 1980.

Offshore, Gravel Island Offers Foundation, p. 189, May 1980.

Offshore, Ice Island Looks Promising, p. 198, May 1980.

Offshore, Vessels to Operate in Ice Areas, p. 212, May 1980.

Offshore, Research Will Uncover Pipe Problems, p. 217, May 1980.

Vetco Offshore Group, Ocean Floor Completion Applications Capability, Technical Bulletin VTB-2-20, 4 pp, March 1977.

Vetco Offshore Group, Early Subsea Production Systems, Technical Bulletin VTB-2-30, 8 pages, April 1970.

Webb, K., A Ship for all Seasons, North, p. 20, May/June 1978.

6.2 References, Chapter 3

American Petroleum Institute, Statistics Related to Onshore and Offshore Wells, unpublished.

Bercha, F. G., and Associates Limited, Probabilities of Blowouts in Canadian Arctic Waters, Economic and Technical Review Report EPS 3-EC-78-12 (Ottawa Supply and Services Canada, 1978), p. 109, *ibid*.

Blenkarn, K. A., and Knapp, A. E., Ice Conditions on the Grand Banks, CIM Special Vol. 10, The Ice Seminar, 61-72, 1969.

Booz-Allen and Hamilton, Incorporated, A Risk and Cost Analysis of Transporting and Storing Gulf of Alaska Outer Continental Shelf Oil, prepared for Environmental Protection Agency, PB-248 739, January 7, 1975.

Canadian Coast Guard, Termopol Assessment of the Kitimat, B.C., Marine Oil Terminal Proposal, Transport Canada Coast Guard, Ottawa, Canada, May 1977.

Card, J. C., USCG, Effectiveness of Double Bottoms in Preventing Oil Outflow from Tanker Bottom Damage Incidents, Marine Technology, January 1975.

Danenberger, Elmer P., Oil Spills, 1971-75, Gulf of Mexico Outer Continental Shelf, Geological Survey Circular 741.

Danenberger, Elmer P., Outer Continental Shelf Oil and Gas Blowouts, U.S. Dept. of the Interior Geological Survey Open-File Report 80-101, 1980.

FENCO CONSULTANTS LTD., Sources of Pollution and Causes of Environmental Disturbance Associated with Canadian Offshore Oil and Gas Production, for Environmental Protection Service, Department of Environment, Canada, May 1979.

FENCO CONSULTANTS LTD., Submission to the Termpol Committee for a Marine Oil Terminal Facility at Kitimat, B.C., for Ocelot Industries Ltd., Vancouver, B.C., Chapter 6, July 1980.

FENCO CONSULTANTS LTD., Lloyd's Register of Shipping, and German + Milne, Arctic Pilot Project Risk/Reliability Study of the Arctic Petro Carriers for Melville Shipping Ltd., Volume VI, Fault Tree Analysis, Proprietary, June 1980.

Ford, R. E., Coast Guard Details Causes of Gulf of Mexico Offshore Blowout, Oil & Gas Journal, p. 134, November 1980.

Golob, R., and McShea, D., Offshore Industry Has Vital Lessons to Learn from Ixtoc 1 Blowout, Offshore Engineer, p. 157, October 1980.

J. J. Henny Co. Inc., An Analysis of Oil Outflows Due to Tanker Accidents, 1971-1972, U.S. Coast Guard, Report No. CG-D-81-74, 1973.

Moser, W. A., Noel, M. P., and Heckard, J. M., Risk Analysis and Oil Spill Expectation for Deepwater Ports, Offshore Technology Conference, Houston, Texas, Paper Number OTC 2450, 1976.

Mundheim, O., et al, Offshore Blowout Control, OTTER Group, Norway, Project No. 880201, February 1981.

Oceanographic Insititute of Washington, Risk Analysis of the Oil Transportation System, PB-244 773, prepared for Oceanographic Commission of Washington, September 8, 1972.

Oil Pipelines Special Task Force No. 1, Spillages from Oil Industry Cross-Country Pipelines in Western Europe, Statistical Summary of Reported Incidents - 1975-1979, November 1976.

Oil Pipeline Performance Review Subcommittee, Canadian Petroleum Association Pipeline Division Oil Pipeline Performance Review 1979, Technical Committee, September 1980.

Porricelli, J. D., et al, Tankers and the Ecology, Trans. SNAME, Vol. 79, 1971.

Ritchie, J. E., Jr., et al, Petroleum Systems Reliability Analysis, Volume I - Engineering Report, Project No. 15080 HOC, EPA-R2-73-280a, August 1973.

Smiley, B. D., and Milne, A. R., LNG Transport in Parry Channel, Possible Environemtal Hazards, Institute of Ocean Sciences, Patricia Bay, Sidney, B.C., 48 pages, 1979.

Thobe, S., Storms are a Major Cause of Mobile Rig Mishaps Offshore, Offshore, p. 23, June 1974.

Welker, J. R., et al, Fire Safety Aboard LNG Vessels, U.S. Dept. of Transport USCG Report No. CG-D-94-76, Office of Reasearch and Development, 1976.

6.3 References, Chapter 4

General

Duval, W. S., and Fink, R. P., The Sublethal Physiology and Behaviour of Selected Marine Fauna, Report for Canadian Environmental Protection Service, Environmental Emergency Branch, F. F. Slaney & Co. Ltd., Vancouver, 86 pp., 1980.

Engelhardt, F. R., Oil Pollution in Polar Bears: Exposure and Clinical Effects, Proc. Arctic Marine Oil Spill Program Tech. Seminar, June 16-

18, 1981, Edmonton, Environmental Protection Service, Environmental Emergency Branch, Ottawa, p. 139-179, 1981.

Environmental Protection Service, Proceedings of the Fourth Arctic Marine Oil Spill Program Technical Seminar, June 16-18, 1981, Edmonton, Environmental Emergency Branch, R&D Division, Ottawa, 1981a.

FENCO CONSULTANTS LTD., and F. F. Slaney and Co. Ltd., An Arctic Atlas: Background Information for Developing Marine Oilspill Countermeasures, For Research and Development Division, Environmental Emergency Branch, Environmental Impact Control Directorate, and the Environmental Protection Service, 1978.

Fink, R. P., Harwood, L. A., and Duval, W. S., The Sublethal Effects of Dispersed Crude Oil on an Estuarine Isopod, Proc. Arctic Marine Oil Spill Technical Seminar, June 16-18, 1981, Edmonton, p. 115-138, Environmental Protection Service, Environmental Emergency Branch, Ottawa, 1981.

Hutcheson, M. S., and Harris, G. W., Sublethal Effects of a Water-Soluble Fraction and Chemically Dispersed Form of Crude Oil on Energy Partitioning in Two Arctic Bivalves, Report for Canada Environmental Protection Service, Arctic Marine Oil Spill Program, MacLaren Plansearch, Dartmouth, 1981.

Imperial Oil Limited, Aquitaine Company of Canada Ltd., and Canada-Cities Service Ltd., Environmental Impact Statement for Exploratory Drilling in Davis Strait Region, 1978.

MacKay, D., Fate and Behaviour of Oil Spills, In, J. B. Sprague, J. H. Vandermeulen, and P. G. Wells, (Eds), Oil and Dispersants in Canadian Seas - Research Appraisal and Recommendations, p. 7-27, Environmental Emergency Branch, Environmental Protection Service, Ottawa, 1981.

Owens, E. H., Coastal Environments of Canada: The Impact and Cleanup of Oil Spills, Environmental Protection Service, Economic and Technical Review Report EPS-3-EC-77-13, 413 pp, 1977.

Percy, J. A., Effects of Chronic Exposure to Petroleum Upon the Growth and Moulting of Juveniles of the Arctic Marine Isopod Crustacean Mesidotea Entomon, Journal of the Fisheries Research Board of Canada 35: pp 650-656, 1978.

Reimer, G. R., An Oil Spill in Pack Ice, C-Core Publication 80/2, Memorial University of Newfoundland, St. John's, 1980.

Biological Oceanography

Apollonio, S., Plankton Productivity Studies in Allen Bay, Cornwallis Island, N.W.T., Woods Hole Oceanographic Institute Unpublished Manuscript In R. A. Buchanan and W. E. Renaud (Eds), The marine ecology of Lancaster Sound and adjacent waters: an annotated bibliography, Department of Indian and Northern Affairs, 1956.

Bain, H., Thomson, D., Foy, M., and Griffiths, W., Marine Ecology of Fast-Ice Edges in Wellington Channel and Resolute Passage, In A. D. Sekerak (Ed.), Studies of the Ecology of Fast-Ice Edges in the High Arctic, LGL Report to Polar Gas Project: In R. A. Buchanan and W. E. Renaud (Eds.), The Marine Ecology of Lancaster Sound and Adjacent Waters: annotated bibliography, Department of Indian and Northern Affairs, 1977.

Buchanan, R. A., Cross, W. E., and Thomas, D. H., Survey of the Marine Environment of Bridport Inlet, Melville Island, LGL Report for Petro-Canada, 1977.

Buchanan, R. A., and Renaud, W. E., (Eds.), The Marine Ecology of Lancaster Sound and Adjacent Waters: annotated bibliography, 262 pp, Department of Indian and Northern Affairs, Ottawa.

Clasby, R. C., Alexander, V., and Horner, R., Primary Production of Sea-Ice Algae, In D. W. Hood and D. C. Burrell (Eds.), (Assessment of the Arctic Marine Environment - Selected Topics), 1976.

Clasby, R. C., Horner, R., and Alexander, V., An In Situ Method for Measuring Primary Productivity of Arctic Sea Ice Algae, Journal of the Fisheries Research Board 30: 835, 1973.

Ellis, D. V., Marine Infaunal Benthos in Arctic North America, Arctic Institute of North America Technical Paper No. 5: 53 pp, In R. A. Buchanan and W. E. Renaud (Eds.), The Marine Ecology of Lancaster Sound and Adjacent Waters: annotated bibliography, Department of Indian and Northern Affairs, 1960.

Grainger, E. H., Biological Productivity of Southern Beaufort Sea. The Physical - Chemical Environment and the Plankton, Technical Report 12a, Beaufort Sea Project, Department of the Environment, 1975.

Hsiao, S. T. C., Biological Productivity of the Southern Beaufort Sea: Phytoplankton and Seaweed Studies, Technical Report 12c, Beaufort Sea Project, Department of the Environment, 1976.

Milne, A. R., and Smiley, B. D., Offshore Drilling for Oil in the Beaufort Sea: A Preliminary Environmental Assessment, Technical Report 39, Beaufort Sea Project, Department of the Environment, 1976.

Milne, A. R., and Smiley, B. D., Offshore Drilling in Lancaster Sound: Possible Environmental Hazards, 95 pp, Institute of Ocean Sciences, Dept. of Fisheries and Environment, 1978.

Northland Associates Ltd., A Preliminary Biological Baseline Description and Environmental Impact Analysis of Blowouts for the Shelf Zone of Newfoundland and Labrador, VII, Report for Department of Mines and Energy, Government of Newfoundland, 286 pp, 1977.

Sekerak, A. D., Buchanan, R. A., Griffiths, W. B., and Foy, M.G., Biological Oceanographic Studies in Lancaster Sound, LGL Report to Norlands Petroleum Ltd., 169 pp, In R. A. Buchanan and W. E. Renaud (Eds.), The Marine Ecology of Lancaster Sound and Adjacent Waters: an annotated bibliography, Department of Indian and Northern Affairs, 1976.

Thomason, D., Woods, S., and Acreman, J., Marine Ecology Survey in the Central Portion of Canadian Arctic Islands, Unpublished, McGill Univ. Report to Polar Gas Project, In R. A. Buchanan and W. E. Renaud (Eds.), The Marine Ecology of Lancaster Sound and Adjacent Waters: an annotated bibliography, Department of Indian and Northern Affairs, 1975.

Wacasey, J. W., Biological Productivity of the Southern Beaufort Sea, 200 Benthic Stidoes, Tech. Report No. 126, Beaufort Sea Project, Department of the Environment, 1975.

Seabirds

Boyd, H., and Maltby, L. S., The Brant of the Western Queen Elizabeth Islands, N.W.T., In R. L. Jarvis and J. C. Bartonek (Eds.), Management and Biology of Pacific Flyway Geese, OSV Book Stores, Inc., Corvallis, Oregon, p. 5-21, 1979.

Brown, R. G. B., Nettleship, D. N., Germain, P., Tull, C. E., and Davis, T., Atlas of Eastern Canadian Seabirds, Canadian Wildlife Serv., Ottawa, 220 pp, 1975.

MacDonald, S. D., Phantoms of the Polar Pack Ice, Audubon 78(3): 2-19, 1976.

MacLaren Marex, Marine Bird Distribution in the Western Labrador Sea, May - October 1979, Report Prepared for Total Eastcan Exploration Ltd., Calgary, Alberta, 500 pp, 1980.

Maltby-Prevett, L. S., Boyd, H., and Heyland, J. D., Observations in Iceland and Northwest Europe of Brant from the Queen Elizabeth Islands, N.W.T., Canada, Bird-Banding 46: 151-161, 1975.

Milne, A. R., and Smiley, B. D., Offshore Drilling in Lancaster Sound. Possible Environmental Hazards, Institute of Ocean Sciences, Patricia Bay, Dept. of Fisheries and Environment, Sidney, B.C., 1978.

Renaud, W. E., and Bradstreet, M. S. W., Late Winter Distribution of Black Guillemots in Northern Baffin Bay and the Canadian High Arctic, Can. Field-Nat. 94: 421-425, 1980.

Marine Mammals

Braham, H. W., and Krogman, B. D., Population Biology of the Bowhead (Balaena Mysticetus) and Beluga (Delphinapterus Leucas) Whale in the Bering, Chukchi, and Beaufort Seas, Report to U.S. National Marine Fisheries Service, 1977.

Davis, R. A., Koski, W. R., and Finley, K. J., Numbers and Distribution of Walruses in the Central Canadian High Arctic, Report for Polar Gas Project by LGL Ltd., 1978.

Davis, R. A., Richardson, W. J., Johnson, S. R., and Renaud, W. E., Status of Lancaster Sound Narwhal Population in 1976, Report to Int. Whal. Commn. 28, 1978 SC/29/DOC 22, Report by LGL Ltd., 1978.

Davis, R. A., Finley, K. J., and Richardson, W. J., The Present Status and Future Management of Arctic Marine Mammals in Canada, Prepared for Science Advisory Board of the Northwest Territories, Yellowknife, N.W.T., by LGL Ltd., 1980.

Fraker, M. A., Sergeant, D. E., and Hoek, W., Bowhead and White Whales in the Southern Beaufort Sea, Beaufort Sea Technical Report No. 4, 1978.

Fraker, M. A., and Bockstace, J. R., Summer Distribution of Bowhead Whales in the Eastern Beaufort Sea, Marine Fisheries Review 42: 57-69, 1980.

Greendale, R. G., and Brousseau-Greendale, C., Observations of Marine Mammal Migrations at Cape Hay, Bylot Island During the Summer of 1976, Fisheries and Marine Service Technical Report No. 680, 1976.

Harington, C. R., Extralimital Occurrences of Walruses in the Canadian Arctic, J. Mammal, 47: 506-513, 1966.

- Kiliaan, H. P. L., and Stirling, I., Observations on Overwintering Walruses in the Eastern Canadian High Arctic, J. Mammology 59: 197-200, 1978.
- McLaren, M. A., and Renaud, W. E., Numbers and Distribution of Marine Mammals Along the Coast of Southeastern Melville Island, July and August 1977, Report for Petro-Canada by LGL Ltd., 1977.
- Milne, A. R., and Smiley, B. D., Offshore Drilling in Lancaster Sound: Possible Environmental Hazards, Report by Institute of Ocean Sciences, Patricia Bay, Sidney, B.C., for Department of Fisheries and Environment, 1978.
- Reeves, R. R., Atlantic Walrus (Odobenus Rosmarus Rosmarus): A Literature Survey and Status Report, Wildlife Research Report No. 10, U.S. Fish and Wildlife Service, 1978.
- Sekerak, A. D., and Richardson, W. J., Studies of the Ecology of Fast-Ice Edges in the High Arctic, Report for Polar Gas Project by LGL Ltd., 1978.
- Sergeant, D. E., and Brodie, P. F., Identity, Abundance, and Present Status of Populations of White Whales, Delphinapterus Leucas, in North America, J. Fish. Res. Board Can. 32: 1047-1054, 1975.
- Sergeant, D. E., and Hay, K., Migratory Sea Mammals Populations in Lancaster Sound, Arctic Islands Pipeline Program Report 1978, ESCOM Report No. AI-21, 1979.
- Sergeant, D. E., Seasonal Movements and Numbers of Cetaceans Summering in Lancaster Sound, Arctic Canada, Int. Whal. Comm. Subcommittee on Small Cetaceans, Cambridge, England, June 22-29, 1979, SC/31/SM 19, 1979.
- Smiley, B. D., and Milne, A. R., LNG Transport in Parry Channel: Possible Environmental Hazards, Unpublished manuscript, Department of Fisheries and Environment, Institute of Ocean Sciences, Patricia Bay, Sidney, B.C., 1979.

Smith, T. G., and Stirling, I., The Breeding Habitat of the Ringed Seal (Phoca hispida), The Birth Lair and Associated Structures, Can. J. Zool. 53: 1297-1305, 1975.

Smith, T. G., Taylor, D., and Haygagiak, Breeding Habitat and Population Surveys of Seals in the Viscount Melville Sound, Barrow Strait, and Peel Sound Areas, Interim Report to the Arctic Island Gas Pipeline Project, 1976.

Stirling, I., An Overwintering Walrus in the Beaufort Sea, The Murrelet 55: 40-41, 1974.

Stirling, I., Andriashek, D., Lafour, P., and Calvert, W., The Distribution and Abundance of Polar Bears in the Eastern Beaufort Sea, Beaufort Sea Technical Report No. 2, 1975.

Stirling, I., Archibald, R., and DeMaster, D., The Distribution and Abundance of Seals in the Eastern Beaufort Sea, Beaufort Sea Technical Report No. 1, 1975.

Stirling, I., Schweinsburg, R. E., Calvert, W., and Kiliaan, H. P. L., Population Ecology of the Polar Bear Along the Proposed Arctic Islands Gas Pipeline Route, Progress Report to the Environmental Management Service, Department of Environment, Edmonton, 1977.

Fishery Resources

Galbraith, D. F., and Fraser, D. C., Distribution and Food Habits of Fish in the Eastern Coastal Beaufort Sea, Interim Report of Beaufort Sea Project Study B1 (Eastern), 48 pp, 1974.

Leim, A. H., and Scott, W. B., Fishes of the Atlantic Coast of Canada, Fisheries Resource Board, Canada Bulletin No. 155, 485 pp, 1966.

McPhail, J. D., and Lindsey, C. C., Freshwater Fishes of Northwestern Canada and Alaska, Fisheries Resource Board, Canada Bulletin No. 173, 381 pp, 1970.

Milne, A. R., and Smiley, B. D., Offshore Drilling in Lancaster Sound, Institute of Ocean Sciences, Patricia Bay, B.C., Department of Fisheries and Environment, 95 pp, 1978.

Nevinsky, M. M., and Serebryakov, V. P., American Plaice Spawning in the Northwest Atlantic Area, ICNAF Res. Doc. 72/103, 25 pp, 1972.

Parsons, D. G., Tucker, G., and Veitch, P., Review of Abundance Indices and Stock Assessment for Shrimp (*Pandalus borealis*) in the Labrador Channels, CAFSAC Res. Doc. 81/7, 41 pp, 1981.

Percy, R., Fishes of the Outer Mackenzie Delta, Beaufort Sea Technical Report No. 8, 114 pp, 1975.

Scott, W. B., and Crossman, E. J., Freshwater Fishes of Canada, Fisheries Resource Board Canada Bulletin No. 184, 966 pp, 1973.

Zilanov, V. K., Stroganov, A., Troyanovsky, F., and Chumakov, A., The Results of the Study of Commercial Reserve of Greenland Halibut (*Reinhardtius Hippoglossoides*) at the Continental Slope in the North-Western Atlantic, ICNAF Res. Doc. 76/VI/109, 20 pp, 1976.

Hunting and Fishing

Arctic Pilot Project, Arctic Pilot Project Socio-Economic Statement North of 60° Latitude, Chapter 5, Part A, p. 129-152, 1978.

Brackel, W. D., The Socio-Economic Importance of Wildlife Resource Utilization in the Southern Beaufort Sea, Beaufort Sea Technical Report No. 32, Beaufort Sea Project, Department of Fisheries and Environment, Victoria, B.C., 91 pp, 1977.

C-Core, An Oil Spill Scenario for the Labrador Sea, C-Core Technical Report No. 78-2, Chapter 8, Resource Utilization and Potential Impact, 1978.

Labrador Inuit Association, Our Footprints are Everywhere - Inuit Land Use and Occupancy in Labrador, Dollco Printing Ltd., 380 pp, 1977.

Labrador Inuit Association, Assessing Movement in an Arctic Caribou Population, J. Environment Management 3, p. 251-257, 1950.

Milton Freeman Research Ltd., Inuit Land Use and Occupancy Project Report, Department of Indian and Northern Affairs, Volume I and III, 1976.

Smith, T. G., and Taylor, D., Notes on Marine Mammal, Fox and Polar Bear Harvests in the Northwest Territories, 1940-1972, Fisheries and Marine Service Technical Report No. 694, 37 pp, 1977.

Taunton, G. F., and Fenton, R. W., Background Information on the Resource Harvesting Economy in the Polar Gas Region, Northwest Territories, 1976, for Polar Gas Project, 57 pp, 1977.

Hypothetical Slick Movement

Canadian Hydrographic Service, Pilot of Arctic Canada, Volumes I, II, and III, Department of Energy, Mines and Resources, Ottawa, 1970.

Fissel, D. B., and Marko, J. R., A Surface Current Study of Eastern Parry Channel, N.W.T., Canada, Department of the Environment, Institute of Ocean Sciences, Patricia Bay, B.C., Contractor Report Series 78-4, 1978.

Fay, J. A., Processes in the Spread of Oil on a Water Surface, Proc. Joint Conference on Prevention Control of Oil Spills, WASHINGTON, D.C., Published by American Petroleum Institute, 381 pp, 1977.

Greene, G. D., and MacKay, D., The Probable Nature and Behaviour of Oil Spills in the Beaufort Sea, and the Feasibility of Clean-Up, In Oil Under the Ice, by Pimlott, D., Brown, D., and Sam, K. (Eds.), Canadian Arctic Resources Committee, Ottawa, Ontario, 1976.

Gundlach, E. R., Berne, S., D'Ozouville, and Topinka, J., Shoreline Oil Two Years After Arrow Cadiz: New Complications, from Tanio, Proc. 1981 Oil Spill Conference, API Publication No. 4334, p. 525, 1981.

Herlinveaux, R. H., and de Lange Boom, B. R., Physical Oceanography of the Southeastern Beaufort Sea, Beaufort Sea Project, Technical Report No. 18, 1975.

J.B.F. Scientific Corporation, Physical and Chemical Behaviour of Crude Oil Slicks on the Oceans, Publication 4290, American Petroleum Institute, Washington, D.C., 1976.

Ledrew, B. R., and Gustajtis, K. A., An Oil Spill Scenario for the Labrador Sea, Technical Report 78-2, C-Core, St. John's, Newfoundland, 796 pp, 1978.

MacKay, D., Buist, I., Mascarenhas, R., and Paterson, S., Oil Spill Processes and Models, Report EE-8 to Environmental Protection Service, Environment Canada, Ottawa, Ontario, 1980.

MacKay, D., and Leinonen, P. J., Mathematical Model of the Behaviour of Oil Spills on Water with Natural and Chemical Dispersion, EPS-3-EC-77-19, Environmental Protection Service, Ottawa, Ontario, 1977.

Milne, A., Oil, Ice and Climate Changes, Department of Fisheries and Oceans, Ottawa, Ontario.

Milne, A., and Herlinveaux, R. H., Crude Oil in Cold Water, Department of Fisheries and Oceans, Ottawa, Ontario.

Okubo, A., Deep Sea Research, 1977.

Peck, G. S., Arctic Oceanographic Data Report 1977 Western Viscount Melville Sound, Unpublished manuscript, Canada Centre for Inland Waters, Burlington, Ontario, 1978.

Peck, G. S., Arctic Oceanographic Survey, Unpublished manuscript, Canada Centre for Inland Waters, Burlington, Ontario, 1979.

Stepney, P. H. R., A Review of Ocean Currents and Surface Winds of Lancaster Sound, Report to Norlands Petroleum Ltd., 1977.

Walker, E. R., Oil, Ice and Climate in the Beaufort Sea, Beaufort Sea Technical Report No. 35, Beaufort Sea Project, Victoria, B.C., 1975.

7. ACKNOWLEDGEMENTS

7.1 List of Companies Contacted for Chapter 2

American Petroleum Institute, Washington, D.C., U.S.A., Research Analysis and Statistics

Arctic Institute of North America, Calgary, Alberta, Library and the Arctic Science and Technology Information System (ASTIS)

Can Ocean Resources Ltd., Calgary, Alberta

Can Ocean Resources Ltd., New Westminster, British Columbia

Dome Petroleum Limited, Calgary, Alberta, Engineering and Design Department, Beaufort Production Development Department

Esso Resources Canada Ltd., Calgary, Alberta, Frontier Section Research Department

F.G. Bercha & Associates Ltd., Calgary, Alberta

J.G. German & Milne Inc., Montreal, Quebec

Gulf Canada Resources Inc., Calgary, Alberta, Frontier Environmental Research Department

Institute of Ocean Sciences, Patricia Bay, Sidney, British Columbia

Leonard Pipeline Contractors, Calgary, Alberta

Lloyd's Register of Ships, Vancouver, British Columbia

Oil and Gas Journal, Tulsa, Oklahoma, U.S.A., Statistics Department

Oilweek Magazine, Maclean-Hunter Ltd., Calgary, Alberta

Offshore Magazine, Houston, Texas, U.S.A.

Panarctic Oils Ltd., Calgary, Alberta, Engineering Department

Vetco Offshore Group, Calgary, Alberta

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